A Strategic and Technological Framework for Sustainable Low-Cost Housing in South Africa

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Declaration

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Abstract

With a vast majority of South Africans living in poverty, they are consequently unable to fulfil their basic needs. This includes the inability to provide adequate housing for themselves and their family. The only solution for most people is to wait for the government to provide them with low-cost housing. As a result, the government is charged with constructing countless homes. Therefore, the government commissioned low-cost housing frameworks, namely the Reconstruction and Development Plan, which comprises of policies, strategies and technologies.

To ensure the construction of these dwellings have a positive effect on the environment, economy and community, it is imperative they be built sustainably. This investigation places South Africa within the context of global sustainability, as a developing country. Furthermore, it examines sustainability in the construction sector and develops an understanding of sustainable buildings. Thereafter, this investigation explores the demand for sustainable low-cost housing in South Africa, and determined there is an abundant need for housing with a high level of sustainability.

To determine whether the existing frameworks perform satisfactorily, this investigation used Kayamandi, Stellenbosch as a case study to draw conclusions from. The case study provided a platform to investigate the existing strategic and technological frameworks prescribed for low-cost housing. These frameworks include the Reconstruction and Development Plan (RDP), the Integrated Development Plan (IDP) the strategy of from the Stellenbosch Municipality and the technological guidelines from the Sustainability Institute.

To investigate the existing technological framework it was necessary to quantify its performance. This would require building-rating tools and assessment. After reviewing numerous methods, this investigation used a building-rating tool prescribed by the Green Building Council of South Africa (GBCSA). Additionally, this investigation examined the literature on Life Cycle Assessments to determine the most efficient method to reduce the negative impacts buildings have on the environment.

With the aid of the building-rating tool, it was possible to investigate the existing strategic and technological frameworks for low-cost housing in Kayamandi. After exploring the existing frameworks of the case study, it was possible to define and examine the shortcomings of the technologies and strategies used to construct low-cost housing.

The measurement of the existing technological framework highlighted that it did not meet the standards of the GBCSA and needed improving. Furthermore, exploring the strategic framework revealed there were fundamental changes that need to occur. Subsequently, this aided in the formation of a new strategic and technological framework.

Once the proposed new frameworks were developed they were compared to the existing ones. To assess the technological framework, the results of the existing and proposed frameworks were compared graphically. It was determined that the proposed framework out-performed the existing framework, meaning it achieved a higher level of sustainability with a similar cost structure and thus validating the effectiveness of the proposed framework. The proposed strategic framework addresses all the shortcomings of the existing framework with additions to further facilitate synergy between stakeholders, government and the people of Kayamandi. Thus, this investigation presents a proposed framework that aims at achieving and enabling long-term sustainability for constructing low-cost housing. Furthermore, it specifies an outline on the necessary actions needed to provide the impoverished people of South Africans with adequate homes.

Keywords: South Africa, low-cost housing, sustainable development

Opsomming

Die groter meerderheid van Suid-Afrikaners lewe in armoede. Gevolglik kan meeste mense nie hulle basiese behoeftes bevreedig nie. Dit sluit die voorsiening van genoegsame behuising vir hulself en hulle familie in. Die enigste oplossing wat baie mense het is om te wag tot die regering hulle met lae koste behuising kan voorsien. Sodoende is dit die regering se plig om groot hoeveelhede lae koste behuising op te rig. Die regering het daarom 'n lae koste behuising raamwerk, genaamd, die Heropbou- en Onwikkelingsprogram , wat uit beleide, strategiee en tegnologiee bestaan.

Om te verseker dat die konstruksie van die wonings 'n positiewe effek op die omgewing, ekonomie en gemeenskap het is volhoubaarheid ononderhandelbaar. Die ondersoek plaas Suid-Afrika, 'n ontwikkelende land, binne die konteks van globale volhoubaarheid. Dit ondersoek volhoubaarheid in die konstruksie sektor en ontwikkel 'n begrip vir volhoubare geboue. Die ondersoek kyk na die vraag vir lae koste behuising in Suid-Afrika en stel vas dat daar 'n oorvloedige nood vir behuising met 'n hoe vlak van volhoubaarheid is.

Om vas te stel of die huidige raamwerk beveredigend werk het die ondersoek 'n gevallestudie, Kayamandi in Stellenbosch, gebruik om tot gevlogtrekkings te kom. Die gevallestudie het as 'n platform gedien om die huidige stretegiese en tegnologiese raamwerke, vir lae koste behuising in Suid-Afrika, te ondersoek.

Om die huidige tegnologiese raamwerk te ondersoek was dit nodig om die produktiwiteit te kwantifiseer. Om dit te kon doen was 'n gebou graderings hulpmiddel gebruik. Daar was vasgestel dat die beste hulpmiddel vir die ondersoek die voorgeskrewe gebou graderings hulpmiddel van die Groen Gebou Raad van Suid-Afrika (GBCSA) was. Die ondersoek het ook die literatuur van die Lewens Siklus Assesering besturdeer om die mees effektiewe metode vas te stel om sodoende die negatiewe impak wat geboue op die omgewing het te verminder.

Met behulp van die gebou graderings hulpmiddel was dit moontlik om huidige strategiese en tegnologiese raamwerke, vir lae koste behuising in Kayamandi, te ondersoek. Dit was sodoende moontlik om die tekortkominge van huidige tegnologiee en stratigiee vas te stel wat in die lae koste behuising raamwerk gebruik word.

Die meting van bestaande tegnologiese raamwerk het beklemtoon dat dit nie die standaarde van die GBCSA behaal nie en drasties verbetering nodig het. Daar was ook openbaar dat die

strategiese raamwerk kardinale verandering benodig. Daaropvolgend, het dit die nuwe strategiese en tegnologiese raamwerk help vorm.

Die voorgestelde nuwe raamweke was met die huidige raamwerke vergelyk. Om die tegnologiese raamwerk te assesseer was die huidige en voorgestelde raamwerke grafies vergelyk. Daar was vasgestel dat die voorgestelde raamwerk die huidige raamwerk ver verbysteek. Die voorgestelde raamwerk het ‘n hoer vlak van volhoubaarheid bereik met ‘n soortgelyke koste raamwerk. Hierdie vergelyking bevesetig dus die effektiwiteit van die voorgestelde raamwerk. Die voorgestelde strategiese raamwerk raak alle tekortkominge van die huidige raamwerk, met toevoeging tot verder fasilitering van die samewerking tussen die belanghebbendes, regering en inwoners van Kayamandi. Die ondersoek stel ‘n raamwerk voor wat streef om lang termyn volhoubaarheid vir die konstruksie van lae koste behuising in staat te stel, asook verarmde mense van Suid-Afrika met voldoende huise te voorsien.

Sleutelbegrippe: Suid-Afrika, lae koste beshuising, volhoubare ontwikkeling

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List of Acronyms

ANC	- African National Congress
BREEAM	- Building Research Establishment's Environmental Assessment Method
CASBEE	- Comprehensive Assessment System for Building Environmental Efficiency
CIB	- The International Council for Research and Innovation in Buildings
CO_2	- Carbon Dioxide
DE	- Demolition Energy
EC	- European Commission
EDGE	- Excellence in Design for Greater Efficiencies
EE	- Embodied Energy
GBCA	- The Green Building Council of Australia
GBCSA	- The Green Building Council of South Africa
HDA	- Human Development Agency
HK- BEAM	- Hong Kong Beam
HVAC	- Heating, Ventilation and Air Conditioning
ICLS	- International Conference of Labour Statisticians
IDP	- Integrated Development Plan
ILO	- International Labour Organisation
IRR	- The South African Institute of Race Relations
ISO	- The International Organisation for Standards
LCA	- Life Cycle Assessment
LCE	- Life Cycle Energy
LCEA	- Life-Cycle Energy Analysis
LED	- Local Economic Development
LEED	- The Leadership in Energy and Environmental Design
MJ	- Megajoules
NHBRC	- The National Home Builders Registration Council
OE	- Operating Energy
PID	- Preferred Investment Destination
PV	- Photovoltaic
R&D	- Research and Development
RDP	- Reconstruction and Development Programme
SDI	- Spatial Development Initiative
SM	- Stellenbosch Municipality
StatsSA	- Statistics South Africa
UN	- The United Nations

UNEP	- The United Nations Environment Programme
UNFCCC	- The United Nations Framework Convention on Climate Change

CHAPTER 1: BACKGROUND

1.1. Introduction

The preservation of the environment has become an increasingly problematic concern on a global scale. As a result, investors and actors on all levels are making concerted efforts to preserve the environment from degradation, so that there might be a future for generations to come.

New concepts, such as ‘sustainable’ and ‘green’, have emerged over the last few decades and have become the focal point of many establishments. These concepts have been introduced either by governmental policy or regulation, or out of genuine discontent. These concerns have surfaced because many basic sectors (namely industry, construction and agriculture) have continually contributed to the degradation of the environment (Lele, 1991). Environmental degradation is caused by the abuse of non-renewable energies, the over consumption of resources and waste pollution. Fortunately, there are numerous avenues to explore to prevent or even reverse the effects of environmental degradation.

This investigation examines sustainability in the construction sector within the context of South Africa as a ‘developing’ country. Specifically, it explores the sustainability in low-cost housing delivery. With a multitude of social, economic and environmental issues present in South Africa, it is imperative for effective strategies and technologies to be implemented to meet these needs. In response to his, this investigation evaluates existing technological and strategic frameworks responsible for the construction of low-cost housing.

This investigation defines ‘framework’ as a basic structure underlying a system, concept or text. The most notable framework for constructing low-cost dwellings in South Africa is called the Reconstruction and Development Programme (RDP). One of the main objectives of the RDP is to align with local municipalities to construct adequate housing for people subject to poor living conditions. Essentially, interlinking local and international housing frameworks. Therefore, this investigation uses a municipality, namely Stellenbosch Municipality, as a case study to perform the basis of its analysis and investigation. Moreover, it explores the level of interaction the municipality’s existing frameworks have with the principles of sustainability.

This investigation primarily focuses on establishing a more sustainable technological and strategy framework for transforming informal dwellings into formal housing. Which essentially focuses on replacing makeshift shelters, like ‘shacks’, and replacing them with adequate residences. It also focuses on providing suitable homes for citizens who require low-cost housing.

The technological framework provides guidelines for selecting technologies to implement in low-cost housing, with a supplementary method to measure the effectiveness of the technologies. Thus, creating a concurrent, measurable approach to achieve resource efficient housing, that is aimed at continually exploring new technological innovations.

The strategic framework aims to provide an outline of necessary actions and linkages to achieve sustainable within low-cost housing delivery. The framework provides approaches to increase synergy between the government, public sector and private sector to stimulate the diffusion of technologies that are socially, economy and environmentally beneficial.

1.2. Sustainable Development

Over the last several decades, the definition of sustainable development has transformed dramatically. In the past, the concept of sustainability has always been understood as rationing supplies, using resources effectively or maximising profits (Martine, *et al.*, 2015). Only in the late 19th century did government and organisations begin to understand the negative implications that continual consumption and development had on the biosphere (Martine, *et al.*, 2015). Since then, it has transformed into the complex system, which will be described further in this Section.

In 1992, an Earth Summit was held in Rio where sustainable development was the main topic for discussion. As a result, Agenda 21 was created, which is a framework for sustainable development that could be implemented internationally. The framework’s function is to help meet basic human needs and pursue those needs in a sustainable manner. The ability to meet most of our basic human needs relate in one way or another to the creation and performance of human settlements (Monto, *et al.*, 2005). As a result, the Habitat Agenda was created in June 2001, by the United Nations General Assembly. It is intended to address the sustainable development of human settlements as well as identify the major impact that the construction industry must play.

In 1999, the International Council for Research and Innovation in Building and Construction (CIB) published its *Agenda 21 on Sustainable Construction* (CIB Report Publication 237, 1999). The main objective of this agenda was to establish a framework and terminology base that could be used globally. Furthermore, the framework acts as a foundation for Research and Development (R&D) activities within the context of sustainable construction (Du Plessis, 2007; Michelman, 2003). The document also highlighted the challenges that the construction industry faced to conform to developing settlements sustainably.

Prior to the fully evolved concept of sustainability was ‘eco-development’, which emerged from the United Nations Conference on Human Environment in 1972 in Stockholm. This term shortly evolved into what is known as ‘sustainable development’ today. One of the more notable publications regarding sustainability is called Our Common Future (WCED, 1987), known as the ‘Brundtland Report’. The publication illustrated the concept of sustainable development that contrasted with the limitation of growth perspective. The report stated:

“*...sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs...*”.

This investigation views sustainable development, highlighted by Du Plessis (2007), as a relationship between the environment (biophysical and social) and humans that occupy it. The relationship pivots around humans being able to meet their needs without exceeding the critical limit of the environment and without obstructing modern ideals of basic human rights and social equity. Du Plessis (2007) further explains that the continual act of sustaining the Earth and its resources, will aid in avoiding social and environmental collapse, ensure the safety of modern society and preserve the existence of human beings as a species.

From this comprehensive description, it is evident that sustainability has three central contributing facets. That is, economic, social and environment, which are commonly known as the three ‘pillars’ of sustainable development. Several authors mention other factors that affect sustainability, such as technical sustainability, biospherical interference and other noteworthy concepts (Hill & Bowen, 1997). However, this investigation will focus primarily on the three fore-mentioned ‘pillars’ of sustainability.

The United Nations Framework Convention on Climate Change (UNFCCC) convened in Paris in 2015. The focus of the conference, known as COP21, was to address sustainability and the issues surrounding global climate change. The parties negotiated a new treaty that commits all countries to pledge their best efforts to reduce the negative effects on the global climate. Countries involved are now also subject to international review regarding their efforts to reduce harmful emissions.

The cause of the climate change can be accredited to the rate at which global societies are consuming natural resources (Burns, 2016). The rapid depletion of resources has caused an alarming increase in greenhouse gasses, which was recognized to be major contributor to the increase in global temperatures. When considering the largest contributor to greenhouse gasses, carbon dioxide (CO_2), the concentration has increased by more than 20% in the last 60 years in most industrialized countries (Nelson, Rakau & Dörrenberg, 2010:3) .

It has been noted there is a great potential for sustainability in the construction sector (Sisson, *et al.*, 2009). The European Commission reports that buildings are responsible for the largest share of the EU‘s final energy consumption (42%) and for about 35% of all greenhouse gas emissions (Nelson, Rakau & Dörrenberg, 2010). The United Nations Environmental Program (UNEP, 2009) claims that buildings are responsible for more than 40 percent of energy use and one-third of green house gasses (GHG) emissions globally. Consequently, if sustainable buildings are implemented on a more regular basis across the globe, their negative effects on the environment will decrease and they will be more economically beneficial over the complete life cycle of the building (Nelson, Rakau & Dörrenberg, 2010:3) .

As a result, there is global pressure to expand the use of sustainable energies and renewable sources of energy that can sustain livelihood. Fortunately, new technologies provide potential for the mitigation of large amounts of energy consumed in this sector. The available technologies could reduce the energy consumption by 30-50 percent, without significantly affecting the value of the investment or the cost of construction (Cheng, Pouffary, Svenningsen & Callaway, 2008).

Energy and GHG mitigation can be achieved through numerous methods. Examples of technologies that can be applied to increase efficiency in buildings include smart design, energy efficient materials, energy regulators, etc. Applying these technologies to each phase the building’s life cycle contributes to the energy efficiency of the structure and its processes. Other methods of energy and GHG mitigation are social issues that are prescribed by policy makers and government. A comprehensive background on South Africa’s policies, strategies and governmental regulations on sustainability can be viewed in Appendix A.

Three Pillars of Sustainability

The function of the pillars of sustainability, within the scope of this low-cost housing, is to enable construction to be more efficient and sustainable. The pillars are divided into three principal sections, namely: social, economic and environmental. Although these sections separately deal with completely different subject matter, they are all imperative to achieve effective sustainability. Each pillar contributes equally in diffusing new sustainable technologies into corporations, government, society, etc. The process of orientating the three pillars to function equally and effectively is often not possible. Figure 1.1 depicts a typical representation of the pillars of sustainability.

For most situations, it is found that trade-offs must be made for a project to be feasible. For example, it would not be advisable to install extremely expensive photovoltaic (PV) panels into low-cost housing. From an environmental aspect it would be a great way to reduce energy consumption, however, socially it would be inequitable, as it would greatly reduce the amount of people able to receive housing subsidies. For a project to function optimally, each pillar would have to synergise with the other two. Furthermore, they would have to be analysed critically for every project to have the desired sustainable impact (Hill & Bowen, 1997). For example, when considering a low-cost house or a multi-story building, constructing either would have vastly different environmental, social and cost challenges.

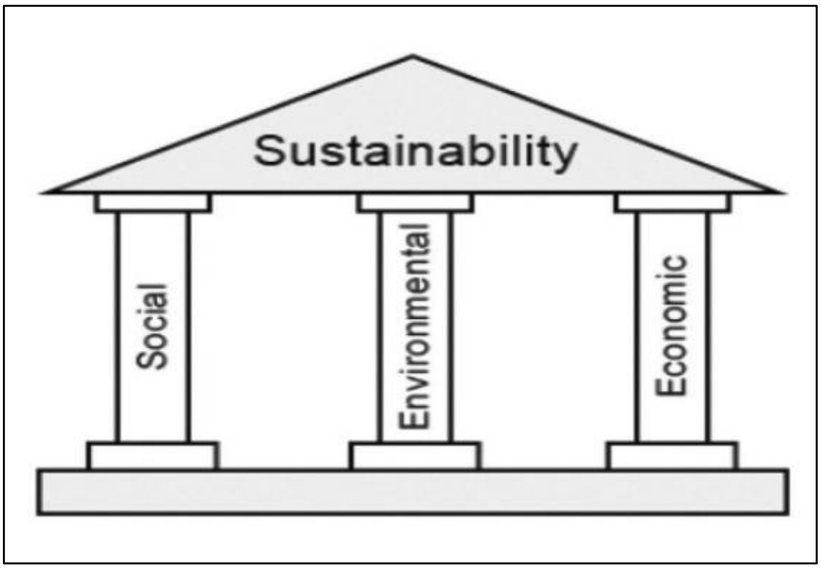

Figure 1.1: Pillars Of Sustainability (Knorr, 2009)

Before a new venture is undertaken it is imperative that the project be viewed as an interconnected system, to understand where sustainable actions will be most effective. Listed below are several consequences that analysing a development as a sustainable system would have:

- Input from previous developments aid in realising where the development can reduce the amount of wasted resources.
- Developments are completed timeously with involved stakeholders participating in the decision-making process.

- Facilitates positive economic growth.
- Aids in effective environmental input from multiple stakeholders and promotes collaboration between them.
- Decreases the carbon footprint of the development from start to after finish.
- Promotes social (gender and racial) equity.
- Enables establishments to manage the progress of the development and monitor sustainable performance during each phase. Thus, contributing knowledge to future developments.
- Decreases the amount of biophysical damage the development does while being constructed and years after completion.
- Increases the reputation of the developer by gaining community and investor confidence.
- Aids in the creation of a sustainable framework and the implementation of it.
- Enables the developers to comply with governmental and municipal policy.
- Facilitates a healthy connection between the environment and the development.
- Recognises the importance of alternate energy sources and promotes the implementation of renewable resources.
- Sustainable infrastructure ensures adequate youth development.
- Supports economic, social and environmental stability.

Although some of the previously mentioned consequences can be considered as less important, they all are necessary and contribute to a certain degree in achieving sustainability. Within this complex synergy, several outcomes are apparent, and sustainability tries to identify and promote the outcomes that support the existence of humanity (Du Plessis, 2007; Khagram, *et al.*, 2003). Additionally, promoting the best quality of life for people in their respective communities, while avoiding biophysical capacity limits.

It should be noted that 'developed' and 'developing' countries would differ on their viewpoints on the outcomes of sustainable development. This is to be expected as their economic, social and environmental circumstances are completely different. The relationship of sustainable development still functions as an interlinked body and dealing with the three pillars will ensure that the desired outcomes are achievable. Figure 1.1 depicts the interconnected relationship model that sustainability has with its contributing facets, all of which fall under the three pillars of sustainable development. The focus of Figure 1.1 is to outline the achievable processes that will enable effective synergy between the multiple facets of sustainability.

1.3. Background on Sustainable Development in SA

According to Khan (1990), historical evidence suggests that the earliest inhabitants of South Africa displayed concerns about their environmental impact and implemented practices to conserve the environment and resources. While there was a concern, South Africans took a very reserved and conservative stance towards sustainable development. Khan (1990) believes this can be linked to the environmental policies and practices of the early 1970s in the Apartheid era. In the late 1970s, the Surplus People‗s Project determined that approximately three million black people were forced to relocate within the Apartheid regime. This resulted from policies such as the Group Areas Act that enforced evictions of non-white tenants to demarcated areas. Thereafter, the ensuing 30 years resulted in the methodical demolition of housing built for non-white in urban areas (Christopher, 1990).

Additionally, the land on which the people were relocated to had limited access to municipal services, was unable to facilitate subsistence farming and as a result infringed on their basic human needs (Labuschagne, 2007). Thus, the apartheid government mostly overlooked sustainable development issues as they prioritised politics. Consequently, this destabilised the housing environment and promoted a housing crisis in South Africa. The post-Apartheid government was later burdened to stabilise the housing sector, and due to the high demand sustainable issues and repercussions are still evident today (GBCSA, 2012).

According to Stats SA (2015), 53.8% of South Africans live in poverty and are unable to meet their basic needs. Essentially, this means there are over 25 million people that are exposed to harsh living conditions. Providing adequate housing for such a large population will prove to be challenging for the South African government and involved stakeholders. Because there are so many houses that need to be constructed, it is imperative that it be built sustainably.

As a result, the high volume of critically poor in South Africa has created a market for sustainable housing technologies to be implemented. Moreover, it has created an environment that enables the immediate penetration of new technologies. That is, "*skipping inferior, less efficient, more expensive or more polluting technologies and industries and move directly to more advanced ones*" (Cascio, 2004), also known as leapfrogging. This has sparked a search for environmentally and economically beneficial technologies to be implemented in the informal housing sector (GBCSA, 2012). This will enable the diffusion of technologies that are similarly economically beneficial.

In the context of developing countries, there is an immense need for large-scale development, specifically in the housing sector. To alleviate this problem, the South African government implemented the Reconstruction and Development Programme (RDP). Part of this programme is to provide formal housing to underprivileged people in informal and formal settlements. Additionally, the government hopes to implement the RDP in a sustainable manner but executing the programme as a government has proved to be difficult (Pottie, 2004).

A significant amount of research and technology is accessible to enable the construction of sustainable and green buildings. These technologies could address South Africa's energy crisis. However, this knowledge is not completely integrated or included in South Africa's existing housing frameworks and strategies. It is imperative that the RDP be implemented in a sustainable manner to preserve and conserve South Africa's resources and energy reserves.

Therefore, the objectives of this investigation are to research frameworks, strategies and technologies that are currently implemented in the RDP. Furthermore, it aims to improve the technologies to facilitate sustainability in low-cost housing. The following chapters review the life cycle assessments of the buildings to further understand where technologies will be most effective once implemented. Moreover, green building rating systems were investigated to obtain a benchmark for comparisons for future housing frameworks.

1.4. Problem Statement

Current strategic and technological frameworks, such as the RDP, IDP and Stellenbosch Sustainability Institute technology guidelines, have numerous benefits (financial, environmental, etc.) but can be improved using more recent advancements. They are environmentally friendly but not sufficiently sustainable for the current and future energy crisis. It is therefore necessary to develop a framework and technological analysis suitable to address the resource crisis that South Africa faces.

As previously mentioned in section 1.1, the Earth's natural resources are under strain and alternate methods of consumption need to be investigated and applied. Consumption during development needs to be conducted in a sustainable manner to preserve the environment and protect resource reserves for future generations. With the need for large-scale, low-cost housing in South Africa and other developing countries, it is imperative that it be done sustainably. This implies constructing housing that is environmentally friendly, energy efficient, cost effective and makes use of sustainable materials. Moreover, it means enabling the growth of informal economies, where informal housing is most prominent.

In South Africa, the central issue is that existing frameworks are out-dated and there is an insufficient amount of sustainable technologies currently implemented into informal housing. Although, it should be noted that sustainable frameworks do exist yet they are not tailored for low-cost housing (Smit & Musango, 2015b:154). The scale of technologies implemented in the existing sustainable frameworks would not be beneficial in smaller dwellings, as the cost would be uneconomical.

There are vast opportunities and potential for informal dwellings to transform into green homes and there is a large scope of green economical functions to help achieve this (Benson, Best, del Pozo-Vergnes, *et al.*, 2014). Moreover, there are numerous sectors that would be involved other than the construction and development sector (Smit & Musango, 2015b: 154) . Thus, there is potential for creating different value streams.

The questions that need to be answered:

- What are the gaps in the existing frameworks for low-cost housing in South Africa?
- Can increased sustainability be achieved in low-cost housing through an improved strategic framework?
- Can technologies available to South Africa be incorporated into such a framework to provide increased sustainability and decrease the strain on resource consumption in RDP housing?

1.5. Research Objectives

By answering the research questions in section 1.4, this investigation aims to develop a strategic framework. The function of the framework is to facilitate the stimulation of more effective mechanisms that aid in achieving greater sustainability in developing low-cost housing. Furthermore, the strategic framework requires validation from academics and developers involved in informal housing.

Additionally, this investigation performs an energy analysis on available technologies. The results are examined for applicability and effectiveness. The technological analysis is compared with the current development in Kayamandi to highlight effectiveness. This is discussed further in Chapter 5. To address the research problem effectively, this investigation proposed to:

- Examine sustainability within the construction sector and develop an understanding of sustainable buildings.
- Evaluate the need for low-cost housing in South Africa

- Investigate methods to quantify and measure sustainability in dwellings.
- Investigate the existing strategic and technological frameworks prescribed for low-cost housing in South Africa.
- Define and examine shortcomings to form a new strategic and technological framework.
- Demonstrate the relevance, applicability and level of sustainability of the new framework.
- Validate the new framework and present results graphically where applicable.

Therefore, this investigation aims to: (1) Develop an understanding for the need of sustainable low-cost housing in South Africa. (2) Create a strategic framework that will meet the aforementioned criterion of sustainability. (3) Analyse the technologies and strategies that could be implemented and the effects they will have on the CO_2 emission mitigation, material usage (embodied energy) and efficient water and energy consumption. The reason for creating a new strategic framework and analysing current technologies is that, with the exponential rate at which sustainable technologies are being innovated, it is necessary to update existing frameworks on a regular basis. In addition, with limited resources in South Africa, the implementation of energy efficient technologies is crucial for future economic stability. Furthermore, once the aforementioned framework is completed, it could act as a benchmark to which alterations and improvements can be made.

There is a significant body of research and technology available about sustainable development and green buildings, namely in East Asia, Europe and the USA (Siva, *et al.*, 2017). Yet, it has not completely integrated into South Africa or been included into existing frameworks, such as the Integrated Development Plan or Reconstruction and Development Programme, (Du Plessis, 2007; Darkwa, 2006). This is discussed in further detail in Chapter 4.

1.6. Importance of Research

Developing informal and low-cost housing is a crucial part of addressing poverty and practicing successful governance in SA. The people within settlements are primarily underprivileged, have minimal access to resources (education, finances, etc.) to improve their circumstances and are victims of unreliable or unavailable basic services. This includes basic needs such as potable water supplies, electricity, effective drainage, refuse disposal, home security, etc., which dramatically affects the residents' health and social security (Garstka, 2010:86).

Thus, inhabitants are vulnerable to limited economic opportunities, gender and racial inequality, loss of homes and poor health care. Addressing informal and low-cost housing is a key aspect to attaining sustainable development in South Africa and formalising and greening the informal economy. The following list summates the importance and the desired effect this investigation aims to achieve:

- Catalyst for green economic development
- Decrease strain on resources and biophysical environment
- Strengthen the national economy
- Increased sanitation and water quality
- Invite foreign investment
- Reduce the effects of climate change (global warming) and improve green 'footprint'
- Promotion of increased employment in all sectors and economies

1.7. Limitations and Assumptions of Research

While preparing for this investigation, there were several limitations that were encountered that ultimately defined the depth and completeness of the analysis. It is generally accepted by most researchers that there is some form of constraint, whether it is time or resources. A combination of the large scope of elements affecting informal and low-cost housing and constraints hindering the investigation meant that a complete investigation of policy and regulation at a provincial level was not possible. However, accepting these constraints did not compromise accomplishing the objectives towards achieving sustainability. The following is a list of limitations and assumptions made that were recognised and accepted by this investigation:

- Time did not permit that every technology available to South Africa be considered. As a result, with the guidance of the Green Building Council of South Africa (GBCSA), only the most efficient and effective technologies were included and thus made it possible to analyse them within the allotted time.
- Data acquired are assumed to be correct from the sources used in this investigation, such as Statistics South Africa (StatsSA), GBCSA, etc.
- Validation: Obtaining a wide spectrum of validation from numerous sources proved difficult because it required willing participation of stakeholders and interested parties.
- Consultants: Obtaining information from willing consultants proved difficult, as many of them did not have time or resources. Additionally, the information obtained was assumed to be correct and applicable.

- It was assumed that government is in support of transforming the informal and low-cost housing into more sustainable communities. Furthermore, that they would be willing to implement proposed results of this investigation.

1.8. Conclusion

A preliminary investigation suggests there is limited literature regarding the amount of R&D on technological and strategic frameworks for residential areas and low-cost housing in South Africa, specifically the Reconstruction and Development Plan (RDP) and Integrated Development Plan.

While the literature suggests there is extensive knowledge around sustainable development frameworks, it is limited to developed countries. Applying the knowledge, strategies and technologies to developing countries is unfeasible, as the countries do not share similar infrastructure, resources, skills, etc. Therefore, it is necessary to adapt or create knowledge, strategies and technologies applicable to a developing country or developing areas within a partially developed country.

1.9. Chapter Outline

The chapters in this investigation discuss the following:

Chapter 1: Introduction and Background

Provides a background and setting of this investigation. It places South Africa in the global dilemma of resource scarcity and climate change. In addition, it highlights the need for sustainable development. The chapter outlines the problem statement and the research objects this investigation aims to achieve. It then concludes with limitations, assumption and importance of the investigation.

Chapter 2: Literature Review

The literature review explores sustainability with respect to defining and understanding sustainable construction and buildings. Furthermore, this investigation explores green-building rating tools and the life-cycle analysis of buildings to quantify and measure sustainability in dwellings. Additionally, this chapter highlights the need for low-cost housing in settlements in South Africa.

Chapter 3: Research Methodology

This chapter defines two primary methods of research, namely qualitative and quantitative. Moreover, it describes the method of research, research strategy, data collection and analysis.

Chapter 4: Case Study of Kayamandi

This chapter provides an overview of the living status, housing, demographic and geography of Kayamandi (settlement in South Africa). It examines the strategic and technological framework employed by the municipality to facilitate the construction of low-cost housing. Additionally, it defines and examines shortcomings of the existing framework to facilitate the formation of a new strategic and technological framework.

Chapter 5: Results and Analysis

This chapter highlights the assumptions made by this investigation to form a technological and strategic framework. Additionally, it presents this investigation's proposed framework. It subsequently demonstrates the relevance, applicability and level of sustainability of the proposed framework. Moreover, it validates the new framework by presenting the results graphically.

Chapter 6: Conclusions and Recommendations

This chapter summarises the proposed framework and explains why it is an improvement of the existing framework. Additionally, it concludes with recommendations and improvements that could be made to this investigation. It concludes with suggestions to future researchers to increase sustainability in low-cost housing.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview

The literature review places South Africa within the larger context of global sustainability, as a developing country. It explores sustainability with respect to defining and understanding sustainable construction and buildings. This chapter provides information on the progress that sustainable development has made since the Brundtland Report. It also highlights the need for low-cost housing in settlements in South Africa.

This investigation explores green-building rating systems and the life-cycle analysis of buildings to develop an understanding of energy flows in dwellings. Furthermore, it explores a green-building rating tool (called EDGE) to quantify and measure sustainability in houses. The tool measures energy consumption, CO_2 emissions, water usage and embodied energy in materials. With the results extrapolated from the tool, it is possible to quantify the sustainable performance of a building.

2.2. Construction

Construction has various definitions, most of which point toward similar meanings, yet have fundamental differences. The definition could restrict it to a single act of erecting a construct, or a broader meaning that involves viewing the entire cycle of the process. According to Du Plessis (2002), the most common understanding of construction is the combination of human and machine labour that result to form a building or erection, e.g. house, bridge or road. This definition describes one of the numerous phases of the entire life cycle of a construction project. Viewing construction only on this level limits technological innovations to be diffused and as a result, a broader understanding is necessary. Figure 2.1 depicts the relationship described by Du Plessis (2002).

In terms of sustainability, practices and technologies are implemented throughout the entire life cycle of a construction project. However, the effects and influence of the construction industry extend past any given project. The industry forms part of a large sector that contributes significantly to any country’s gross domestic product (Behm, 2008:175). It acts as an enabler for many other commercial sectors to thrive, such as the material and transport sector, and secures national and foreign investors. The construction industry also provides the necessary infrastructure to strengthen an economy and increase the quality of life by providing essential services to the community, such as hospitals or schools. It creates a livelihood for millions of people in any country and has a tremendous impact on society.

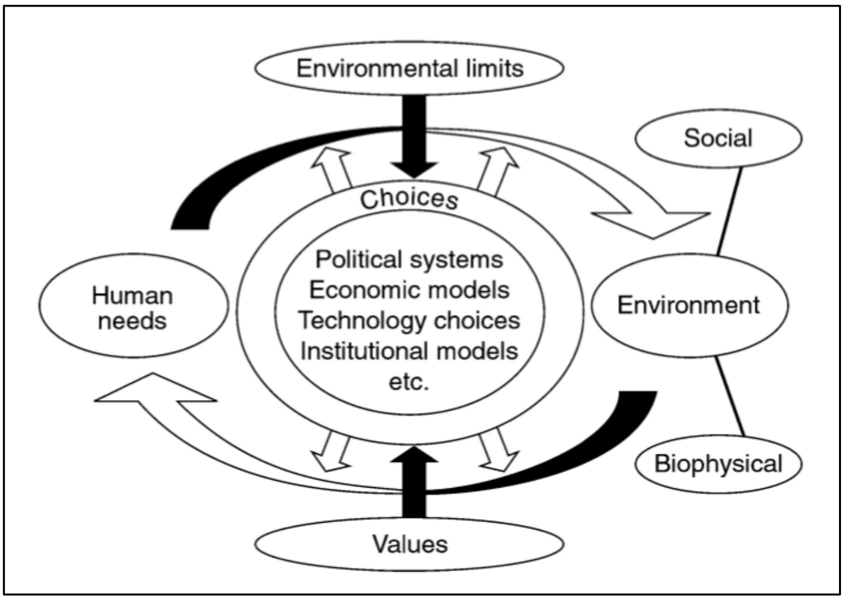

Figure 2.1: Relationship Model of Sustainable Development (Du Plessis, 2007)

To completely capture the entire understanding of construction, Du Plessis *et al.* (2002) recommended it be defined as follows:

"Construction is the broad process/mechanism for the realization of human settlements and the creation of infrastructure that supports development. This includes the extraction and beneficiation of raw materials, the manufacturing of construction materials and components, the construction project cycle from feasibility to deconstruction, and the management and operation of the built environment."

With the construction industry proving to have a tremendous influence on numerous sectors of any country and the world, it therefore contributes significantly to the use of resources and to the production of GHGs. As previously mentioned, globally it accounts for more than 40 percent of energy consumption and one-third of green house gasses (GHG) emissions (UNEP, 2009). Reducing these figures will prove to be challenging, however, it is necessary for the continued survival of humans as a species.

2.3. Sustainable Construction

The term 'sustainable construction' was initially proposed in 1994 at the First International Conference on Sustainable Construction in Tampa, United States of America. Kibert (1994a) was among the first to introduce the concept, and also named it 'green construction'. Kibert (1994b) also defined sustainable construction as *'creating a healthy built environment using resource-efficient, ecologically-based principles'*.

The principles that Kibert (1994c) proposed for sustainable construction are: conserve consumption, reduce waste, reuse renewable resources, recycle waste effectively, the protection of nature and mitigation of toxic material (Bakhtiar, Li & Misnan, 2008:55). This placed emphasis on the design phases of the construct and the methods implemented to ensure that resources were used efficiently without compromising the wellbeing of the inhabitants and the surrounding environment (Shen, Ou & Feng, 2006) . The emphasis is very similar to that of sustainability and as such, it is considered as a subset of sustainable development (Bakhtiar, Li & Misnan, 2008:55) . Figure 2.2 depicts the relationship sustainable construction has between the life cycle, Kibert's (1994c) principles and the resource requirements.

More recently, Kibert (2007) defined sustainable construction to include how the construction industry, including the existing built environment, contributes to the sustainability of the biospherical wellbeing of the Earth. However, it should be noted that the construction industry is increasingly contributing to the environmental degradation of the earth placing strain on renewable and non-renewable resources and endangering species by driving them to extinction (Bakhtiar, Li & Misnan, 2008:55) .

A foreseeable problem of defining sustainable construction, would be mistaking it for the definition of sustainability. The International Union for the Conservation of Nature and Natural Resources defined sustainable activity as a continual endeavour lasting forever. (Kibert, 2007) Therein lies the problem because a construction project cannot fall within those boundaries, as it is finite (Hill & Bowen, 1997:223). It is generally accepted that sustainability in construction is from 'cradle to grave', which will be highlighted in section 2.9. Regardless of the differences, researchers and developers have continually attempted to create more common ground between sustainability and construction.

The construction industry has evolved dramatically since the 1990s. Previously the focus of sustainable construction was placed primarily on technical issues, i.e. environmental impact assessments, on site building materials and machine functioning and developed technologies (Shen, Ou & Feng, 2006). In recent years, it has been accepted that sustainable construction extends further than the diffusion of technological innovations, such as policy, codes of practice, management efficiency, etc. This has birthed new strategies that are aimed at addressing effective approaches to include stakeholder participation (Shelbourn, et al., 2006). Stakeholders may include investors, civil engineers, contractors or material manufacturers.

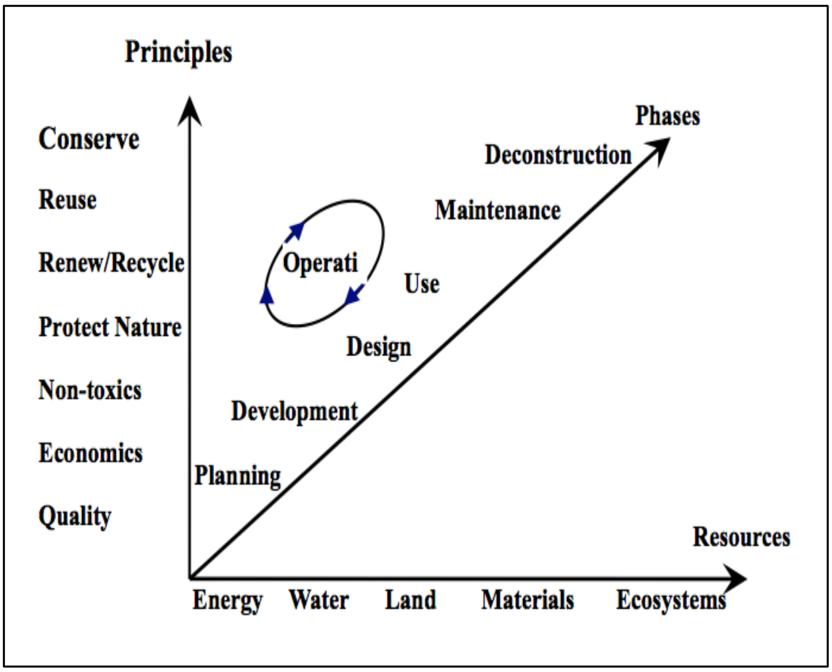

Figure 2.2 Sustainable Construction: Life cycle, Principles And Resource Requirements (Kibert, 1994c)

There has been international cooperation to shift the construction industry to a sustainable movement (Shen, Ou & Feng, 2006). Although the industry is new to sustainable ideals, it has begun to shift onto a parallel path with the principles of sustainability. There is a global recognition that implementing and monitoring sustainability is a major contributor to a fully functional construction business. According to Shelbourn *et al.* (2006) key performance indicators, environmental performance indicators and the implementation of benchmarking are becoming common practice in the international construction industry. Furthermore, construction companies are increasingly producing sustainability and environmental impact reports and assuming corporate social responsibilities.

2.4. Green Buildings

A basic definition of a green building is a construction that is beneficial both economically and environmentally. According to Nelson *et al.* (2010), a green building is more intricate than simply implementing eco-friendly measures; the building is enhanced by better air quality and greater access to natural light, which also raises workers 'productivity. Waste minimization and less dependency on increasingly scarce and expensive fossil resources also lower the operation costs.

By international standards, the purpose of a green building is to limit the amount of CO_2 emissions associated with construction and the operation of a building (Ghaffarian, *et al.*, 2013). In addition, it is noted that the energy performances of the green buildings have an enormous effect on the sustainability of the built environment.

Typically, green buildings, make use of renewable energy sources such as solar, wind and waves, and have effective systems that convert waste into useable energy. With the influence of innovation, the end goal of green buildings is to approach complete energy efficiency, i.e. to rely completely on renewable energy sources to support the functions of the construct (Ghaffarian, *et al.*, 2013).

Internationally there has been some confusion to define a green building, as various countries differ on how they classify the sustainability. Each country has its unique set of strict building codes and governmental regulations that it must adhere to. Therefore, finding an international standard has proven to be an intricate process. One aspect that remains a constant is that there has been a shift toward a more sustainable built environment with the purpose of decreasing fossil fuel consumption, and thereby mitigating CO_2 emissions (Nelson, *et al.*, 2010).

2.5. Low-Cost Housing Within Formal and Informal Settlements

Formal, in the context of settlements and housing, is described by Christopher (1990) as an area designated for housing, by local or national authority, which is provided public services and amenities to sustain basic needs, such as sanitation and electricity. Contrarily, an informal settlement is a collection of housing that was erected on land not designated by local authority and consequently does not receive public services. Formal and informal settlements have numerous sub-classifications, namely Urban and Rural, which are discussed below. A common attribute the two types of settlements have is that both contain low-cost housing (makeshift or government built).

Low-cost housing has several definitions within a global context primarily because countries have dissimilar economies, social infrastructure and environmental challenges (Gunter & Manuel, 2016:312). For example, a developed country, such as the USA, may define low-cost housing as cheap cluster housing, whereas a developing country would define it as the slums. However, the universal function of low-cost housing is to satisfy the basic needs of people, incapacitated either by financial turmoil or external influences, such as war (Dijkstra & Poelmann, 2014:2014). It is evident that low-cost housing is prevalent in informal settlements and forming an understanding of these settlements is imperative to adequately address low-cost housing as a whole.

Informal settlements were recognised by the International Labour Organisation (ILO) in a report that was published in 1972. The report defined informal settlements as localities that produced activities conducted by the poor to maintain livelihood and were not regulated by local authority. Thus, the methods a community used to sustain a livelihood was not recorded, protected or monitored by the government or local municipalities (Essop & Yu, 2008:1). According to the ILO (1972), these activities have numerous definitions that predominantly indicate entry-level type enterprises. These enterprises are realised by using local resources and skills (e.g. subsistence farming). The type of operations is small-scale and generally do not require any form of tertiary education for them to be competitive in local markets.

The definition has changed since the ILO published their report in 1972, as the global economy and markets have evolved similarly. The focus of the definition proposed by the ILO was directly related to employment status of individuals. This proved to be difficult to quantify the informal settlements and its activities, also known as informal sector, as majority of the informal enterprises did not monitor employment statuses and were essentially self-employed. In addition, it was challenging to estimate the amount of people involved, as they were not recognised by local authorities.

Therefore, in 1993 at the International Conference of Labour Statisticians (ICLS), it was proposed that the definition of the informal sector focus primarily on the number of informal enterprises rather than employment status of individuals (Essop & Yu, 2008:1) . The ICLS also included flexibility in the newly agreed upon report. Previously, the ILO did not include non-registered enterprises or employees, domestic or agriculture employees and the number of employees allowed at any given informal enterprise (ILO, 1993). Throughout the years, the definition has been altered several times by numerous bodies. Therefore, it attempts to cater for the intricate evolution and types of livelihood present in the informal sector.

In South Africa, it is difficult to measure the sum of all the informal activities, as there are no official statistics or information that will aid in the classification and measurement (Essop & Yu, 2008:1). As a result, a definition of the informal sector as recommended by Stats SA (2011), focused on the criteria of enterprises that have a non-registration status, as mentioned in the 1993 ICLS definition. Figure 2.3 is a depiction of the methodology used by StatsSA to classify whether a person is part of the informal or formal sector.

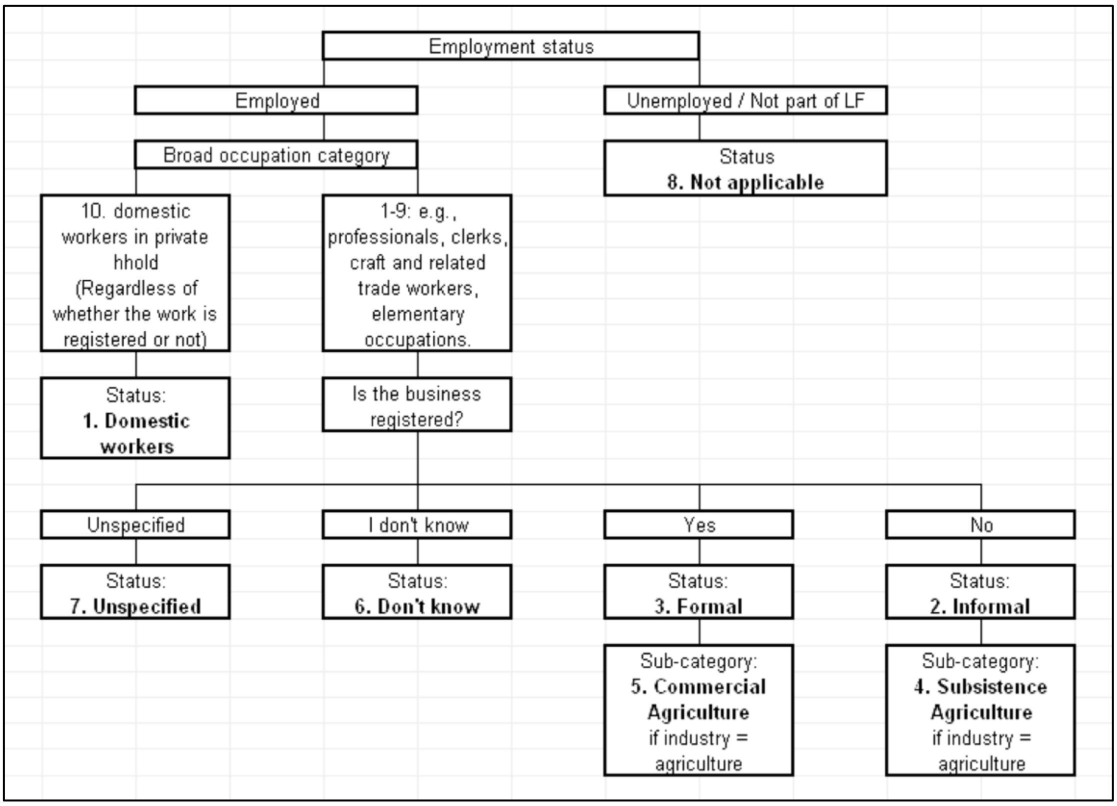

Figure 1.3: Employment Status Definition (Essop & Yu, 2008)

Although this is an effective method to classify the size and status of people in an economic standing, it does not necessarily hold true for their living standards (Saunders & Loots, 2015:92) . There are many of the sub-groups that will have similar living standards, for example, being self-employed does not necessarily mean a person lives in a formal or informal settlement and furthermore does not indicate financial stability. Therefore, it is necessary to distinguish informal activities from settlements.

To classify whether activities and settlements are informal or formal, depends on numerous aspects. This investigation briefly discusses several that are relevant to developing a framework for low-cost housing. In the following sections, this investigation will review aspects that categorise housing and settlements as candidates for the proposed framework.

2.5.1. Rural and Urban Areas

The United States Department of Health and Human Services defines rural as “all population, housing, and territory not included within an urban area. Whatever is not urban is considered rural”. Like the definition for low-cost housing, it is expected that the definition of ‘urban’ and ‘rural’ differ in each country. Numerous countries use population to distinguish between urban and rural areas, yet there are still irregularities when considering this method of classification (Dijkstra & Poelmann, 2014). According to Medani (2016), it is widely viewed that urban areas are classified as non-agricultural areas. This does provide some form of relevant classification; however, the definition would be more applicable from the perspective of industrialised countries. From the perspective of South Africa, it is common to find areas of industry located near farmlands.

A traditional approach to view the difference between rural and urban areas is to assess the standard of living of the inhabitants (Christopher, 1990:421). It is generally assumed that the quality and standard of living in an urban area is far superior to that of a rural one. Yet again, there are irregularities with this method as there is no base case or 'lowest limit' of an urban area. Using this classification in a developed country often blurs the distinction between the two regions, as both would have similar standards of living and industry, with the only difference being population density (Medani, 2016).

Although the standard of living in developing countries across rural and urban areas is vastly different, this approach provides inconsistencies as urbanisation occurs at a rapid rate. When standard of living or capita are inadequate methods of measurement, it may be supplemented by the size of the settlement yet is circumstantial to specific countries.

The United Nations (UN) has stated that a method, applicable across the globe, to classify an area as rural or urban has not been established (Medani, 2016). Moreover, there are no recommendations on the classification of regional areas, as each country should establish their own distinctions that correlate with their specific needs. The UN has provided guidelines that aid in distinguishing a region as urban: the area should be a separate conglomeration of people; the inhabitants should live in adjacent dwellings and the demarcated region should have a name or be recognised locally. Although the guidelines do aid with classification, it could be argued that it would only be applicable in extremities.

The South Africa Municipal Demarcation Board has difficulty providing distinction between different areas (Stellenbosch Municipality, 2014). This is owing to the rate of urbanisation occurring over the last 20 years and the merging of 'rich' and 'poor' areas created by the apartheid government (Christopher, 1990:421) . It is prevalent that a region demarcated as a rural one, would expand to a nearby urban area or increase exponentially in population without any municipal functions and support required for cities or towns. Therefore, it has continually complicated the process of defining regions on a national or local scale.

According to the most recent Census published in 2011 South Africa is comprised of the following regions:

- 9 Provinces
- 52 District Councils
- 232 Municipalities
- 12435 Main places/Towns

It is expected that categorising so many towns and municipalities prove to be challenging. To complicate matters further, each region comprises of numerous settlement types that occupy large surface areas and do not fall within a specified demarcated area. Statistics South Africa (StatsSA, 2011) provides 10 categories in which localities may be categorised. The categories are formal residential, informal residential, traditional residential, farms, smallholdings, commercial area, industrial area, collective living quarters, parks (parks, recreational areas and state parks) and vacant land (StatsSA, 2011).

Although the categories provide adequate descriptions of regions, misclassifications often occur. According to Medani (2016), there are misinterpretations of what defines a locality owing to a lack of administration and regulation. Furthermore, using the data currently available in the Census may prove inadequate and monitoring the populations may be necessary as localities are often overlooked.

The UN and the European Commission (EC) have highlighted methods to classify regions. The UN categorises regions and localities primarily by number of capita. Particulars of the prescribed method are depicted in Table 2.1. The EC focuses predominantly on population density, as depicted in Table 2.2.

Majority of the time, authorities in South Africa will find difficulty implementing the method proposed by the UN. Difficulties would occur with areas being incorrectly demarcated, expansion without formal guidelines and civil divisions between settlements (Medani, 2016). As for the method provided by the EC, South African authorities would experience similar issues that affect the UN method. Additionally, issues surrounding areas being incorrectly identified localities would complicate the method further.

Table 2.1: UN Locality Classification (Medani, 2016)

Name	Number of capita
Metro or major city	500 000 or more
City	100 000 to 499 999
Town	20 000 to 99 999
Large village	5000 to 19 999
Small village	1000 to 4999
Settlement	Up to 999

Table 2.2: European Commission Locality Classification (Dijkstra & Poelmann, 2014)

Urban-Rural	Name	Population identity	Description	Definition
Urban	City	Densely populated	100% high-density clusters	*High-density clusters:* >1500 people per 1km^2 >50 000 total population
	Urban centre	Densely Populated	>50% high-density clusters Residual urban clusters	*Urban clusters:* >300 people per 1km^2 >5000 total population
	Towns	Intermediate density	<50% high-density clusters <50% rural grid cells	*Rural grid cells:* > 0 people per 1km^2 > 0 total population
	Suburbs	Intermediate density	<50% urban clusters <50% rural grid cells	
Rural	Rural area	Thinly populated	> 50% rural grid cells	

With respect to South Africa, there are numerous rural environments that are on the fringe of urban environments (Smit & Musango, 2015a:1). Stellenbosch and Kayamandi, two areas in the Western Cape, illustrate this predicament clearly. The border between the two areas is blurred, with Stellenbosch considered an urban area and Kayamandi a rural one. Therefore, numerous studies are needed to classify areas across South Africa. StatsSA conducted the most notable study by using information gathered from the Censuses in 1996, 2001 and 2011. An example of the results obtained from the study is depicted in Figure 2.4 The figure illustrates the urban classifications of the Western Cape in 1996 and compared them with 2001. Included in the Figure 2.4 are misclassified areas, which were subsequently correctly identified.

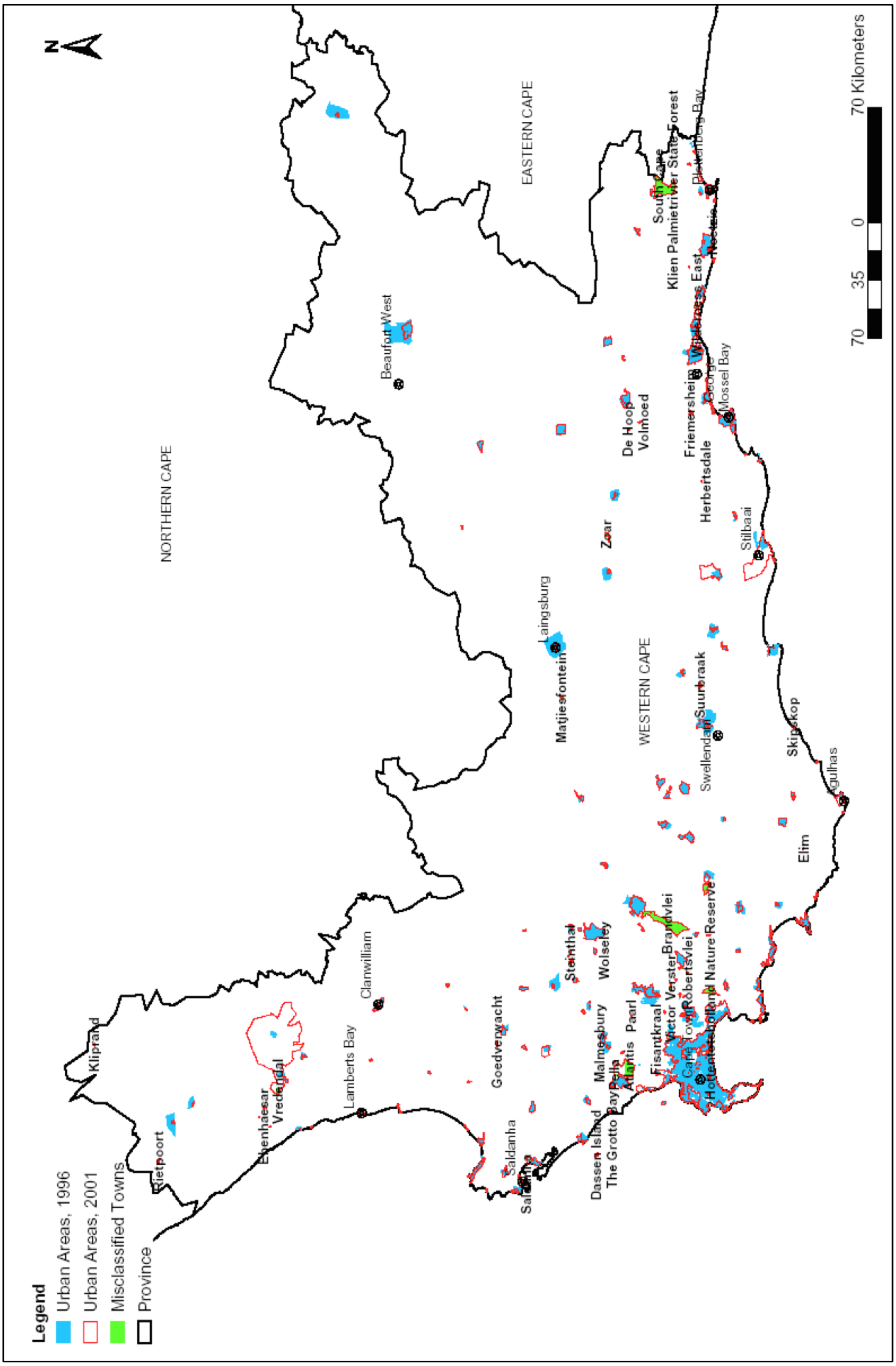

Figure 2.4: Western Cape Urban Areas (Source: StatsSA, 2011, Census, 1996, 2001)

It is evident from Figure 2.4 that StatSA, like numerous international bodies, has included major city centres and townships as urban areas. This deduction was made because the results include the entire City of Cape Town as an urban area. Yet, an informal settlement called Kayelitsha falls within the boundaries of the City of Cape Town. It is a vast township; where inhabitants generally reside in improvised housing made from scrap material, construction rubble and/or tin sheeting. These types of residential areas are very common throughout South Africa and require intervention from government to provide adequate housing. Therefore, implementing a framework in rural areas will not cover the spectrum of people in need of housing.

It should be noted that numerous countries and international authorities recognise rural areas as informal settlements. Yet, as previously mentioned, rural and urban have vastly different definitions and numerous methods on classifying them. Due to the considerable amount of uncertainty with categorising different settlement types and numerous locality classifications, this investigation explores defining 'informal settlements' in greater detail. This provides a better platform for the analysis and implementation of low-cost housing in both informal settlements and formal settlements because, as previously mentioned, the borders between the two settlements are blurred in South Africa. Additionally, the definition of informal takes on a wider variety of meanings as opposed to formal.

2.5.2. Definitions of Informal Settlements

Defining an informal settlement is difficult as there are conflicting view points as to what constitutes a demarcated area to be informal. There are many variances of the definition for informal settlements, ranging from built houses to dwellings purely made of tin. Table 2.3 depicts several definitions, from noteworthy sources, that were summarized in a report published in 2013 by the Human Development Agency (HDA) (HDA, 2013).

It is apparent from Table 2.3 that the definition of an informal settlement, in some instances, extends further than merely the quality and functionality of the dwelling or homestead. Therefore, when developing a framework, it is necessary to consider all these factors, which form an essential part of sustainable development.

Table 2.3: Definitions Of Informal Settlements (HDA, 2013)

Data Source	Definition of Informal Settlements
Statistics South Africa	"An unplanned settlement on land which has not been surveyed or proclaimed as residential, consisting mainly of informal dwellings (shacks)."
City of Cape Town Metropolitan Municipality	The City of Cape Town has adapted the same definition that is outlined by Stats SA.
City of Tshwane Metropolitan Municipality	"Informal settlement means one shack or more constructed on land, with or without the consent of the owner of the land or the person in charge of the land." "Shack means any temporary shelter, building, hut, tent, dwelling or similar structure which does not comply with the provisions of the National Building Regulations and Building Standards Act, 1977 (Act 103 of 1977), the regulations promulgated under that Act and the Municipality's Building Control By-laws and which is primarily used for residential purposes."
National Department of Human Settlements	"The 2009 National Housing Code's Informal Settlement Upgrading Programme identifies informal settlements on the basis of the following characteristics: Illegality and informality; Inappropriate locations; Restricted public and private sector investment; Poverty and vulnerability; and Social stress"
Modimolle Local Municipality (Limpopo)	"Informal settlements are 100% tin houses."
Nelson Mandela Bay Metropolitan Municipality	"An informal settlement refers to one or more shacks constructed on land with or without the consent of the owner of the land or the person in charge of the land. In some settlements, no formal layouts have been approved whilst in others there are formal sites. Services are communal in nature."

2.5.3. Informal Housing vs. Informal Settlements

Informal settlements and informal housing are often used interchangeably, yet they are fundamentally different. Distinguishing the difference between the two terms is necessary to effectively address the issues mentioned in the problem statement and adequately satisfy the objectives of this investigation. Section 2.5.2 has comprehensively defined 'informal settlements' within the context of South Africa. This investigation surmises that the fundamental focus of defining something as an 'informal settlement' is centred on the unregistered land on which housing is constructed, irrespective of the quality of the dwelling.

A brief definition of informal housing is, a dwelling constructed using limited skills and tools, typically by the inhabitants of the abode. The materials used include rubble, tin, clay, mud and wood pieces. Generally, these materials are not used in safe practice to avoid health structural degradation. Occasionally discarded building materials are used, provided the builder understands how to use them correctly (Du Plessis, 2007).

Informal housing can either be located on a legally demarcated or designated area (formal location) or located illegally on a plot not belonging to the inhabitants or demarcated as a residential area (informal location). In both instances, regardless of location, the construction of the dwelling does not adhere to proper building practices. Therefore, informal housing is centred on the quality of the structure and whether it was built according to the regulations of the National Home Builders Registration Council (NHBRC).

2.5.4. Housing Waiting Lists and Subsidies

According to the 1996 Constitution of the Republic of South Africa (Michelman, 2003), every citizen has the right to the access of "adequate housing". Unfortunately, a clear majority are unable to provide themselves and their families with suitable homes. As a result, the government have accepted the responsibility to do so. The national government allocates resources, both money and land based, to citizens without satisfactory living quarters. The responsibility also falls upon local municipalities and provincial legislators. The goal set out by the Reconstruction and Development Program (RDP) is to construct 300 000 low-cost houses per year across South Africa (HDA, 2012).

The RDP is part of the socio-economic policy framework that is focused specially on providing houses to people part of the informal sector (Gunter & Manuel, 2016:312). The framework was created and implemented in 1994 by the African National Congress (ANC) under the presidency of Nelson Mandela. According to the South African Institute of Race Relations (IRR), the government has provided more than 2.5 million houses since beginning of the RDP policy. The IRR also states that the backlog for housing has increased from 1.5 million (2006) to 2.1 million (2011) units, with a corresponding 650% growth in the number of informal settlements (Gunter & Manuel, 2016:312) . That is, 300 to 2 225 settlements. It should be mentioned that although the number of informal settlements has increased by 650%, their contribution to the total national percentage of all settlements has decreased.

Table 2.4 summarises the amount of people per province on waiting lists for RDP housing. The table also indicates the number of years the individuals have been waiting for housing from the state.

Table2.4: Waiting Lists For State Housing (HDA, 2012)

Waiting list for RDP houses		
Province	**Estimated households with a member on the waiting list**	**Average number of years on the waiting list**
South Africa	457 559	5.01
Eastern Cape	52 911	6.02
Free State	30 120	2.99
Gauteng	215 890	5.57
KwaZulu-Natal	43 380	4.32
Limpopo	13 036	2.73
Mpumalanga	25 609	3.22
North West	20 523	3.27
Northern Cape	8 289	3.06
Western Cape	47 801	6.10

According to the Western Cape Government (HDA, 2012) if members of the household have a total income that is less than R3 500, they can qualify for a housing subsidy. There are also other criterions on which candidates can qualify, such as physical and mental health, dependants, age, marital status, etc. A maximum subsidy in 2015 was worth R87 000, which has increased from R12 500 since 1994. However, the houses that are delivered are often inadequately constructed and numerous inhabitants have stated that they are able to build superior quality houses themselves with the given subsidy (IRR, 2015).

2.6. Informal and Green Economy

Although it is difficult to define, the concept of informal economy was revived in SA in recent years because of the increase in size and importance of the activities that occur within the informal economy (Saunders & Loots, 2015:92). The activities provide necessary income opportunities for people in developing countries and are a means to support their livelihood. According to Smit & Musango (2015b), the activities within an informal economy range from trading and minor service operations on pavements, transport interchanges, homes and temporary stalls, to agricultural activities situated in rural and urban localities. These activities barely contribute to a country' gross national product or gross domestic product and as a result are difficult to quantify (Saunders & Loots, 2015:92).

The International Labour Organisation (ILO) defines informal activities as economic actions, performed by people or businesses, that the law or professional practices do not sufficiently protect or cover (Rogerson, 2007). This implies that numerous informal activities do not comply with government policy and labour laws or any regulations enforced by authoritative institutions.

It is recognised by Rogerson (2007) that the 'informal economy' is known by several alternate terms such as grey economy, informal sector, shadow economy, informality or second economy. Whichever term is used to identify this sector, it remains that the informal economy contributes significantly to the overall economy of a country (Smit & Musango, 2015b:154) . In numerous developing countries, the informal economy is responsible for up to 72% of the employment, therefore having a significant role in sustainable development (Smit & Musango, 2015b:154).

20 years after the Brundtland report was released in 2012, the UN held a conference in Rio de Janeiro (Rio+20) regarding the environment and development. This is where the term 'green economy' was introduced (Loiseau, Saikku, Antikainen, *et al.*, 2016:361). This concept was presented to act as a catalyst to promote and ensure sustainable development. Additionally, it was created to address the climate and financial issues experienced on a global scale.

According to the United Nations Environment Programme (UNEP), the purpose of the green economy is to improve the social status, well-being and equity of a country's citizens, while diminishing environmental degradation and ecological hazards (Loiseau, Saikku, Antikainen, *et al.*, 2016:361). The government in SA has recognised the green economy as a means to transform the existing economy to one that mitigates carbon emissions, consumes resources effectively and efficiently and creates employment for the underprivileged (Smit & Musango, 2015a:1) .

The informal economy plays a significant role in sustainable development and the green economy acts as a catalyst to promote it. Thus, the two concepts are consequently connected. However, the two concepts are not in complete harmony as there is; (1) insufficient interpretation and recognition of the informal economy's role within the green economy (2) inadequate structures and mechanisms to integrate them, and (3) division and disconnection between the general policy interlinking them (Smit & Musango, 2015a:1). Therefore, there are several characteristics present in the informal economy that are significant in the creation of a green economy, as discussed in section 2.6.1.

2.6.1. Characteristics of Informal Economy Significant to Creating a Green Economy

Economic:

According to Chen (2012), many systems within the informal economy are interlinked with the formal sector through a series of complicated exchanges. Furthermore, these exchanges include interactions between open exchange markets, manufacturing and transfer of technological products, value chains, the flow of agricultural goods and financial transactions.

Current regulations that overlook operations within the informal economy often negatively impact the green economy (Chen, 2012). A more thorough and complete approach in formalising the informal economy is required as well as the re-evaluating and adjusting macro-economic policies (Benson, *et al.*, 2014).

Socio-economic:

Chen (2012) states, there is a global increase in employment potential in the informal economy and will most likely be a major source of income for people in developing countries. According to Benson, *et al.* (2014) the extent of the informal economy in SA is significantly reducing. Nevertheless, it acts as a financial safety net for people experiencing unemployment within the green economy. Furthermore, the informal economy possesses an important role during a national financial crisis and therefore should be more adequately integrated into regulation and legal structures.

The nature of informal economies is that they are closely linked to their communities. They produce complex social networks that function outside of legality and are based on trust and morality (Benson, *et al.*, 2014; Smit & Musango, 2015b:154). Although the networks in reality create a platform for conflict and dishonest exchanges, they alleviate the pressures of poverty and create protection barriers against financial turmoil. For a green economy to transcend the divide between informal and formal economies, larger social networks would be necessary (Smit & Musango, 2015b:154).

Eco-economic:

People involved in the informal economy use their minimal resources to deal with the extreme weather conditions using innovative designs constructed from inexpensive raw materials. It is suggested by (Smit & Musango, 2015b:154) that local organisations and establishments invest in innovations created by the people within the informal economy. This could act as an effective tactic that produces innovations specific for dealing with constant climate change. Additionally, organisations would no longer have to rely only on innovations that filter from the top down (Smit & Musango, 2015b:154).

The informal economy and settlements experience a close connection with ecological services and have been found to have the strongest connection within clusters of dense poverty (Blignaut *et al.*, 2008). Connecting the supply provided by ecological services within poverty areas, to the demand in formal markets may result in livelihood and employment opportunities. This would have a positive impact on conserving the biophysical environment and decrease the need for social welfare provided by the government (Blignaut *et al*., 2008).

As previously mentioned, people within informal economies can easily adapt to the effects of climate change and inadvertently produce strategies relevant to managing alternating weather conditions. These 'green strategies' are found within numerous informal communities and include energy efficient technologies, effective waste management methods, formal farming and sustainable usage of building materials (Loiseau, Saikku, Antikainen, et al., 2016:361) . This could lead to the creation of 'green jobs' that focus on designing technologies, which prove to be effective within an informal environment, to be transferred and implemented into the formal economy.

2.7. Issues Surrounding Sustainable Development

According to Du Plessis (2002), issues surrounding the implementation of innovations in the low-cost housing have hindered the growth of the market and therefore, the demand. Addressing the issues effectively will be achieved by a joint effort by government, and the private and public sectors. Majority of the R&D technologies is not necessarily shared among the general community, as it would be economically advantageous for a corporation to withhold the valuable information (Dao, *et al.*, 2011).

Even though a technology would be economically beneficial, it would have environmental issues to address. For example, if a new concrete is developed that is just as strong as normal concrete, but at half the price, what would be the environmental impact of the new product? A newer technology is not necessarily better for the environment. As a result, there are environmental impact assessments that can be performed to ensure that key issues are addressed.

Issues generally present themselves as all three of the pillars of sustainability. For example, social and environmental issues are equally important when diffusing technology for economic gain. Therefore, the invention of technology is impractical unless it can be effectively implemented by employing the correct strategy and framework. The following key issues, highlighted by Du Plessis (2002) and Serpell, *et al.* (2013), are the primary hindrances to achieving sustainability in housing. It should be noted that the issues contribute equally to sustainability and are of an environmental, economic and social nature.

- Formalising informal settlements.
- Increased sustainable technologies in subsidized housing.
- Innovation in building technologies.
- Modernising the traditional.
- Education; infrastructure, limited teachers and poor syllabus
- Gender and racial equity
- Innovation in construction methods
- Financing and procurement
- Governance, policy and management
- Needing a new model/framework for development

2.8. Green Building Rating Systems

Globally there are hundreds of building-rating systems being implemented; according to Nguyen, *et al*., (2011), there are over 380 registered building rating tools worldwide. They are aimed at addressing the sustainable issues (economic, environmental and social) surrounding the life cycle of a building. These systems include LCA, environmental impact assessments, efficiency analysis, maintenance optimization, etc. (Sinha, Gupta & Kutnar, 2013) .

For a rating system to add sustainable value during design to demolition, it should offer plausible alternatives that can be implemented. To achieve this, it needs to evaluate relevant technical properties, have a consistent basis for comparison and be relatively simple to comprehend and implement.

Although there are a vast number of rating systems, only a few are globally recognised and provide a satisfactory standard of rating. Following is a brief description of five highly acknowledged rating systems. They were selected based on their global popularity and applicability to this investigation.

- Building Research Establishment's Environmental Assessment Method (BREEAM). BREEAM is widely used throughout the United Kingdom. Although it has been implemented for several decades, the current system is not available to the public but may be purchased through a licenced building evaluator. The building is rated on quantifiable achievements that score points on the rating system. Various alternative rating systems have based their core rating system on the BREEAM software (Fowler & Rauch, 2006) .

- The Leadership in Energy and Environmental Design (LEED).
  The LEED is a voluntary rating system recommended and used by the United States Green Building Council. The focus of this rating system is to ensure excellent environmental performance of a building. LEED evaluates the design and construction phase of a building and has been operating since 1998 (Sinha, Gupta & Kutnar, 2013) .

- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)
  CASBEE is a rating system that was developed in Japan and was made available in English. The system requires documented results that are only issued by professional architects that have passed the CASBEE examination (Fowler & Rauch, 2006). It was designed to improve the quality of living, and reduce energy and resource consumption for the entire building life cycle.

- Hong Kong Building Environmental Assessment Method (HK-BEAM)
  HK-BEAM was developed in 1996. It promotes voluntary rating and is currently the largest voluntary-based rating system in the world. It is aimed at indicating, measuring and improving environmental performances of construction and buildings to promote environmental sustainability (Sinha, Gupta & Kutnar, 2013).

- Green Star
  The Green Building Council of Australia (GBCA) launched this voluntary-based rating system in 2003. Green Star is dedicated to transforming the manner in which the built environment is designed, constructed and operated. The rating system attempts to improve environmental efficiencies in buildings and the health of its inhabitants (Fowler & Rauch, 2006).

Table 2.5 provides a summary that illustrates the adequacy and relevance of the five previously mentioned rating systems. The criteria were rated separately; with several of them carry different weightings based on the importance deemed by Nguyen & Altan (2011).

Table 2.5: Summary of five rating systems (Nguyen & Altan, 2011:376)

Criterion	BREEAM	LEED	CASBEE	Green Star	HK-BEAM
Popularity and Influence	10	10	6	5	5
Availability	7	7	7	8	8
Methodology	11	10	13	9	11
Applicability	13	13	11.5	10	9
Data Collecting Process	7	7	6	9	8
Accuracy and Verification	8	7	9	5	5
User-friendliness	8	10	6	8	8
Development	8	8	7	8	8
Results Presentation	3	3	4	3	4
Total (/100)	**75**	**75**	**69.5**	**65**	**66**

The aforementioned rating systems provide adequate measures of a building's sustainable performance. These systems are beneficial as they can be applied before a building is erected, by inserting the building layout details and specifications into a rating tool. The tool then highlights any areas of the building that are performing unsustainably with regard to energy and resource consumption. This provides the developers with enough time to perform the necessary alterations. An overview of the rating system and tools on South Africa is described in the Section 2.8.1.

2.8.1. Green Rating System and Tools in South Africa

The Green Building Council of South Africa (GBCSA), which is an extension of its Australian counterpart, is a non-profit organisation established in 2007. They are the official rating system in South Africa, should a new, existing or refurbished building require a sustainable certification (GBCSA, 2012). The GBCSA offers online tools, training, information and networks to facilitate greener practices in the construction industry of South Africa (SA).

The rating tools made available by the GBCSA are applicable to different sectors, including retail, residential, public, education, etc. A list of the tools the GBCSA offers, with a brief description of the tools' applicability and measuring capabilities, is listed below:

- Green Star

  The GBCSA develops the Green Star SA rating tool to provide an objective measurement for green buildings in South Africa and Africa (GBCSA, 2012). The tool recognises and rewards environmental leadership in the building industry. Green Star has 4 major categories (tools) that could be used for buildings in South Africa, including the Office Tool, Retail Tool, Public and Education Tool and Multi-Unit Residential Tool. These tools are used to analyse buildings in the design phase based on their tender drawings. Once the analysis is complete, buildings are awarded a star rating out of 6, based on their performance. Only buildings with 4 stars and higher are awarded a certification.

- Existing building are assessed using the Existing Building Performance Tool (EBPT). This tool assesses the environmental performance and operations of any type of existing building. Unlike the new building tools, this is an 'as-built' tool only. The rating is valid for a period of 3 years in order to ensure the building is continually well operated and maintained.

- Energy Water Performance (EWP)

  In response to the demand of the South African property sector, the GBCSA began the development of this energy and water bench-marking tool for existing office buildings (GBCSA, 2012). The EWP tool is an operational performance measurement tool that rates the performance of a whole office building, by comparing the energy and water usage figures against a national "average" benchmark. This tool also assists building owners to understand their office building performance in relation to other similar office buildings in industry, as well as in relation to other buildings in their own portfolio. This helps building owners make decisions on which buildings to retrofit, retain in their portfolio or sell (GBCSA, 2012).

- Excellence in Design for Greater Efficiencies (EDGE)

  EDGE, which is funded by the International Finance Corporation, is a building-rating tool available online and offers a measurable way to reduce the resource intensity of a building. The online platform quickly allows users to determine the financial viability and green aspects of their projects. This tool is able to measure the performance for a wide range of building types, namely residential, commercial, industrial, etc. The tool measures energy consumption, water, embodied energy and carbon dioxide mitigation. EDGE accurately calculates the building's inputs and outputs by using locally adjusted data across utility costs, data climate and building regulations (GBCSA, 2012).

The above tools are based on the design of a building, the implemented technologies and retrofitting existing ones. According to the GBCSA, the objectives of these tools are to (GBCSA, 2012):

- Create a common denominator for the standards of international rating tools.
- Facilitate the integration of greener technologies into the entire building design.
- Acknowledge environmental leadership.
- Create and expand awareness within the construction industry.
- Promote the benefits of the implementation of greener technologies.
- Reduce the environmental degradation caused by the building sector.

To perform the analyses on the existing and proposed technological frameworks, this investigation used the EDGE building-rating tool. This tool was selected because it is recommended by the GBCSA for smaller dwellings. Additionally, the EDGE tool uses locally adjusted data from utility costs, climate statistics and building regulations (GBCSA, 2012). This helps provide the user with a realistic, concurrent evaluation and performance of a building in South Africa. Other globally recognised building rating tools, such as BREEAM and LEED, do not include South African data as completely as EDGE does and consequently were not considered in the analyses.

EDGE primarily focuses on three aspects, including materials, water and energy efficiency. It is also used to calculate the utility savings and reduced carbon footprint of the technologies implemented into a building. Furthermore, the tool provides a selection of the latest technologies that could be applied to a homestead to increase the overall building performance. The tool rates the building's sustainability after a specific technology has been applied. For example, if a dwelling were to install water saving showerheads, the water consumption would be 3.71% percent more sustainable.

Once a building achieves 20% less energy consumption, water consumption and reduction in embodied energy in materials, it is eligible to receive an EDGE certification (GBCSA, 2012) issued by the Green Building Council of South Africa. Furthermore, owners of the building may be entitled to additional cost reductions from government once the certification is acquired. For non-residential buildings, the EDGE software displays the amount of money the technologies will cost and the time it would take the operational costs to cover it (GBCSA, 2012).

The applicability of the EDGE tool is for newly constructed homesteads could be fitted with numerous technologies recommended by the tool to achieve a high level of sustainability. As previously mentioned, South Africa is in need of millions of subsidized homes and the Government can incorporate this technology to achieve future sustainability goals.

2.9. Life Cycle Assessment

A life cycle assessment (LCA) is a method to quantify the material and energy flows of a building throughout its entire life span and during each stage of development. It is a systematic tool that analyses the environmental performance of the complete building process, including feasibility, design, sourcing and transport of materials, construction, operation/maintenance, decommissioning, demolition, and disposal/recycling of waste. Additionally, global and environmental impacts are estimated (such as CO_2 emissions, ozone depletion, eutrophication and acidification) based on the life-cycle energy requirements, waste production, etc. (Ramesh, Prakash & Shukla, 2010:1592) . This investigation chose to place emphasis on LCA because it is imperative to understand where the primary source of energy consumption occurs in buildings and the construction of new homes. Moreover, it will enable a more effective application of technologies.

The concept of LCA was recently introduced into the construction industry, with major advancements starting in the 1970s to the 1980s (Cabeza, Rincón, Vilariño, Pérez & Castell, 2014:394) . In 1997, the International Organisation for Standards (ISO) included an environmental impact approach in their 14 000 standards and similar approaches were introduced by other international organisations. The ISO 14 040 (1997) defined LCA as:

"...a technique for assessing the potential environmental aspects associated with a product (or service) by compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with these inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study".

In the construction industry, LCA methods are used to assess the overall environmental impact of the building. This proves to be challenging, as there are a wide variety of materials, building techniques, energy-saving technique, etc. that have different environmental criteria (Ramesh, Prakash & Shukla, 2010:1592) . Moreover, building developments in modern day society affect more than one type of industry due to their size and scope.

As a result, materials, energy flows and processes have the potential to be unique for a specific development. This limits LCA methods being used as benchmarks in the construction industry. In an attempt to include all these factors, a Life-Cycle Energy Analysis (LCEA) is conducted on each development to decrease environmental impact. Section 2.9.1 further describes the processes involved in preforming a LCEA.

2.9.1. Life Cycle Energy Analysis (LCEA)

LCEA is an assessment method that accounts for all energy flows of a building, during its entire lifecycle. The assessment falls within three primary system boundaries: manufacturing, operational and demolition phase (Ramesh, Prakash & Shukla, 2010:1592). The activities within the manufacturing phase includes the processes and flows that materials follow, including raw material acquisition, production of building products, transport and construction.

The activities within the usage phase comprise of the operating systems within the building shell, primarily for the comfort or benefit of the inhabitants (Ramesh, Prakash & Shukla, 2010:1592). Finally, the activities within the demolition phase include the demolition of the building and removal of all the resultant debris to recycle plants or land fill sites. Figure 2.5 depicts the system boundaries in which the energy flows during the lifecycle of a building.

The total energy used within the system boundary phases can be summated and set equivalent to the total Life Cycle Energy (LCE), as described by:

$$LCE = EE + OE + DE$$

Where,

EE - Embodied energy

OE - Operating energy

DE - Demolition energy

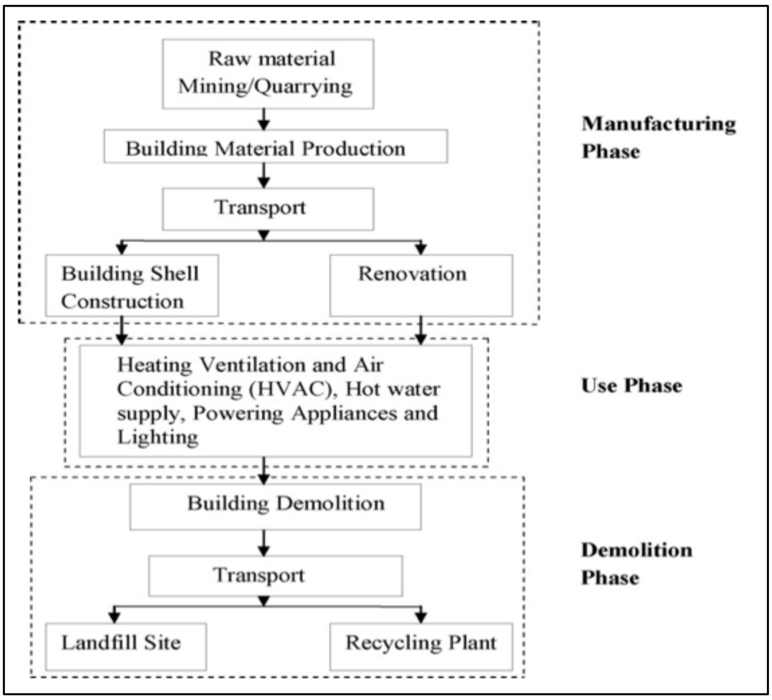

Figure 2.5: System Boundaries For Life Cycle Energy Analysis (Ramesh, et al., 2010)

The Embodied Energy (EE) is the energy consumed during the manufacturing phase. It is the energy utilised by the materials during transport and building, the energy used to erect the building and any alternate installations, maintenance and renovations (Ortiz, *et al.*, 2009).

Operating Energy (OE) is the energy required to support human activities and maintain the functions of a building on a daily basis. It is the energy consumed for heating, ventilation and air conditioning (HVAC), lighting, geysers, operating electronic hardware, etc. OE can vary depending on the climate, comfort and quality of appliances (Hernandez, *et al.*, 2010).

Demolition Energy (DE) is the energy incurred once a building is destroyed because it has reached the end of its purpose or come to the end of its life. DE is the total energy required for demolition and transporting the rubble to landfills or recycling plant (Hernandez, *et al.*, 2010).

By completing an LCEA, it highlights the entire energy expenditure of the construction process. This enables energy reducing methods and systems to be applied to increase energy performances of the buildings and their three phases. Additionally, it identifies the activities of the building life cycle that obtain the highest energy expenditure. Consequently, this enables the amount of GHG to be determined, as emissions from the household sector are very closely connected to the energy one (Karakosta, 2015). Thus, the LCEA remains an effective method for quantifying a building's environmental performance.

Ramesh, et al. (2010) conducted several case studies to quantify the chief contributor to the Life Cycle Energy Analysis. The case studies covered a variety of climates, geographic locations and other factors that could contribute to the LCEA. The results of the studies showed that the chief contributor to the LCEA was the operating energy of the buildings. Ramesh, et al. (2010) noted that an almost linear relationship between the total energy consumption of a building and the operating energy, as depicted in Figure 2.6.

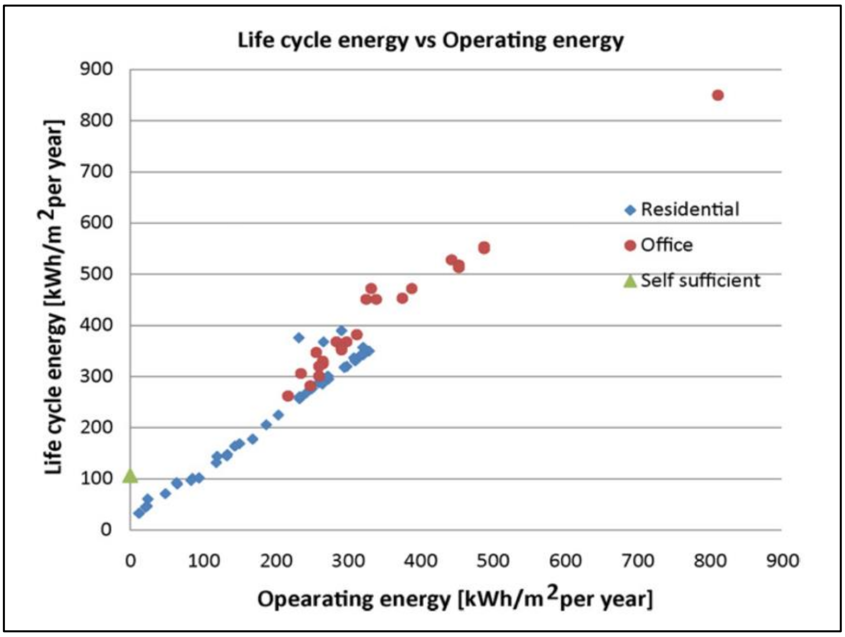

Figure 2.6: Life Cycle Energy vs. Operating Energy (Ramesh, et al., 2010)

It has been concluded that operating energy accounts for approximately 90% of the energy consumed by a dwelling during its life cycle (Ramesh, et al., 2010, Hernandez, et al., 2010, Ortiz, et al., 2009). Therefore, focusing on reducing operational energies can significantly reduce a dwelling's lifetime energy demand.

2.10. Conclusion

This chapter highlighted sustainability in the construction sector and as one of the world's greatest energy consumers and green house gas emitters, the construction sector has an enormous task in transitioning to sustainability. Fortunately, with new technological innovations, methods and materials developed daily, the shift to constructing green buildings is possible.

The review of settlements and low-cost housing was conducted in this chapter. It highlighted the abundant need for low-cost housing in South Africa. Therefore, it is imperative that sustainable practices be properly exercised as it will have an enormous impact on the environment, economy and social well-being of South Africans.

This chapter investigated green-building rating tools and the Life Cycle Assessment of buildings and concluded that these are viable methods to quantify and measure sustainability. Additionally, these methods are able to identify where excessive energy consumption in buildings occurs. Moreover, with measures like a Life Cycle Energy Analysis and building-rating systems, it is possible to identify key issues and challenges to address them accordingly with the principles of sustainable development. Furthermore, these systems enable developed and developing countries to apply technologies effectively and help reach their goals highlighted at World Summits.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Overview

This chapter describes methods and implications thereof in this study to achieve the objectives. It focuses on describing the approach, the strategy that was used, the data collection and the analysis methods.

3.2. Qualitative Research

Qualitative research is based on developing a social understanding of individuals and how they respond to different realities. Rather than analyse numbers to deduct conclusions, this research method focuses on human interaction with a problem of a social nature (Bricki & Green, 2007).

There are several qualitative research approaches that all differ in their types of sampling methods. Each method has a specific purpose depending on the requirements of the investigation. In this investigation, various sampling methods are used when obtaining data, namely intensity sampling, criterion sampling and stratified purposeful sampling.

According to Strauss & Corbin (1990), there are three major components of qualitative research. Firstly, there is data collected using methods such as interviews, observations, documents, records, etc. Secondly, there are various procedures that can be used to interpret and represent the data, to illustrate the objectives of the research problem. This generally consists of a method called coding, which is, conceptualizing, reducing, elaborating and relating (Strauss & Corbin, 1990). Finally, there are written and verbal reports. This comprises of scientific articles and journals, conference papers and books. This investigation also employs a quantitative research method and is briefly discussed in Section 3.3.

3.3. Quantitative Research

Quantitative research can be defined as a mathematical representation of a specific phenomenon (Johnson, et al., 2008). This includes majority of fields in science, economics, mathematics and biology. The method collects measurable data and analyses it using mathematical models. The results are generally displayed as a computed number or percentage. The data that is collected does not necessarily occur naturally in a measurable form. A non-quantitative phenomenon can be altered into a computable form using measurement instruments and techniques (Sukamolson, 2005).

From the definition, it is possible to divide quantitative research into four definite components. Firstly, the researcher is confronted with a phenomenon that needs explaining, which is generally presented in the problem statement or questions. Secondly, the phenomenon is to be transferred, if not already, into a numerical set or sets of data. Thirdly, the data is analysed with the use of mathematical based models. Finally, the results are interpreted and represented usually as statistics to provide understanding (Nunan, 1992).

There are numerous approaches to quantitative research, with each having their own separate characteristics and procedures. Sukamolson (2005) highlights a few useful approaches, namely survey research, correlational research, experimental research and causal-comparative research. This investigation employs a quantitative research method, which is briefly discussed in the following section.

3.4. Research Review Method

This investigation used a narrative review in presenting the relevant information. Thus, the information collected was systematically extracted based on a specific aspect discussed in this paper and summarised. The summation of the information primarily focused on the findings, methods and results of other authors. The investigation employed a qualitative research approach when examining existing frameworks, as the information is extracted predominantly from published articles, journals, various data types and expert consultations.

Intensity sampling was used to evaluate dwellings where little to no technology was implemented in comparison to dwellings that had several technology measures implemented. Criterion sampling was applied by evaluating dwellings that did not meet a predetermined level of sustainability that is highlighted by the Green Building Council of South Africa. Moreover, stratified purposeful sampling was applied by sampling a formal settlement that has informal housing.

This investigation also employed a quantitative research method by attaining statistical results from Statistics South Africa (StatsSA) and numerical data from the green rating tool mentioned in Chapter 2. Furthermore, the information gathered from the quantitative research was used to formulate a technological framework. The research method was used to highlight the relationship technology has with the economy and the environment. This was important to emphasise in the research as it establishes rationale and validation.

The purpose of using a quantitative and qualitative approach is to connect the general emphasis of the author's topics of discussion, address the familiarity between them and focus it on sustainable development in low-cost housing.

3.5. Research Strategy

This investigation used Stellenbosch as a case study, specifically the area on the outskirts called Kayamandi. The settlement is in the Western Cape, South Africa. The area is under the governance of the Stellenbosch Municipality. Using Kayamandi as a case study (1) enables this investigation to employ various approaches for data collection and analyses, (2) provides opportunity of innovation, (3) provides a platform to challenge existing frameworks (from the RDP and Stellenbosch Municipality), and (4) enables effective measurement of implanted technologies. The details of Kayamandi are described in greater depth in Chapter 4 and in Appendix B.

This investigation researched technologies and strategies currently implemented to construct low-cost housing in Kayamandi. That is, the existing technological frameworks prescribed by the Stellenbosch Municipality and the Reconstruction and Development Programme. This aided in examining and defining the shortcomings of frameworks implemented in South Africa and the case study, Kayamandi. Additionally, information was gathered from numerous sources, including academic articles, websites and online tools and data. This aided in the formation of a new strategic and technological framework.

To properly grasp the effectiveness and details of the strategies and technologies used in the low-cost housing, information was gathered from a professional consultation at the GBCSA and schematics of the dwellings obtained online. This provided clarity on the various areas that needed improvement as well as focus the research data collection. Additionally, this investigation used schematics and data from a housing strategy proposed by the Sustainability Institute, located in Stellenbosch. The institute is focuses on quality house delivery, which applies the principles of sustainable development (Stellenbosch Municipality, 2014).

3.6. Data Collection

The data collected was based on the performance, technological implementations, energy and resource usage, and of the strategic framework that is currently being used in the Reconstruction and Development Programme (RDP) and the Stellenbosch Municipality. The data collected provides validity to the argument that current frameworks and technologies are out-dated. The data is also specifically chosen to aid in illuminating the shortcomings that need improving.

In this investigation, research was based on professional consultations, statistical data, qualitative data and quantitative data. The consultations were open-ended with no structure to aid in the flow of necessary information. Consultants were selected explicitly for their sustainable design ability and knowledge of the RDP and low-cost housing. Further sampling and data collection involved direct observation, to understand the effects and full extent of the effectiveness of the implemented frameworks. Additionally, previous data was collected from literature covering similar investigative topics.

The following is a list of the data collection methods, as well as the research sampling methods, that were used to complete this investigation:

- Literature: published articles were extracted from online databases, namely Scopus, Google Scholar and Science Direct.
- Internet sources: published and unpublished sources of information were obtained through various websites and search engines.
- Computer applications: certain data and results were extracted from building rating systems to quantify the level of sustainability of the RDP dwellings and to correlate the effects of new innovative technologies.
- Observation: information was gathered from an informal settlement. This was used in correspondence with documented information to facilitate a better understanding of current frameworks being implemented.
- Consultation: meetings with members of several construction firms that deal with low-cost housing. To become acquainted with policy, social, environmental and economic issues surrounding framework implementation.
- Statistical and quantitative data acquisition: using statistics (StatsSA) to attain data with regards to the living conditions of informal settlement inhabitants in South Africa.

In the settlements, observations were conducted with the highest form of sensitivity. Moreover, consultations were handled with discretion and care when formulating the questions; this was to ensure that the correct information was transferred without any manner of misunderstanding or unethical treatment.

The aims of the consultations were to understand the shortcomings of the existing technological and strategic frameworks. Also, to gain recommendations for new technologies and strategies to be incorporated into this investigation’s proposed frameworks. The consultations were generally broad based and within various settings. Yet, to ensure that relevant information was collected, all the consultations included the following questions within the context on South Africa and the case study:

- Do existing technological frameworks achieve a sufficient level of sustainability?
- What technologies could increase the sustainable performance of low-cost housing?
- If any, what are the shortcomings of the existing strategic frameworks?
- What drivers, mechanisms and performance measures could facilitate increased sustainability?

3.7. Data Analysis

An analysis of the data collected was conducted, to better understand the sustainability of the framework used in the RDP and case study. Thereafter, it was examined, tabulated and compared (see Chapter 4). The data analysis aided in understanding of the current sustainable techniques used by government and similarly involved corporations. It also aided in quantifying the sustainable performance of RDP dwellings and where improvements could be made.

The purpose of the analysis was to (1) quantify the shortcomings of the existing strategic frameworks, which consequently aided in the development an improved framework that facilitates an increased level of sustainability (2) use the EDGE building-rating tool to measure the performance of the existing technological framework and the compare it to the proposed technological framework.

The results are graphically represented to completely understand the progressive effects these technologies have on the environment and economy (as seen in Chapter 5). This will ensure that future designs and technological innovations will be implemented effectively, to increase the sustainability rating of the building.

3.8. Methodology Summarised

This investigation places sustainable development within a global context and then in the context of South Africa. This aided in outlining the objectives and importance of the research. Moreover, qualitative and quantitative research methods were used to explore sustainable construction, focusing on low-cost housing. This facilitated developing methods and strategies to improve sustainability.

Once a foundation was established, this investigation used a case study to explore the strategy and technologies applied in low-cost housing in South Africa. Close emphasis was placed on the technology employed in low-cost housing, as well as the strategy used to effectively build the dwellings to promote sustainability. Once a thorough analysis was completed using the aforementioned online tools, the sustainable performance of the Reconstruction and Development Plan dwellings were tabulated. Thereafter, this investigation's proposed technologies (to be implemented in low-cost housing) were also analysed and the results were tabulated. The results of the two dwellings are compared graphically to provide visual aid on the effects new technologies will have. Included in the graph is the sustainable performance percentage a dwellings needs to have to be certified by the Green Building Council of South Africa.

After the technological analysis, the strategic framework currently implemented to construct RDP dwellings in Kayamandi was scrutinized. The shortcomings of the existing strategic framework were identified and a new strategic framework was proposed to promote more sustainable construction. The complete methodology of this investigation can be summarised as follows:

Research methodology for strategic framework

1. Review national policy and strategy for providing low-cost housing in South Africa
2. Analyse the case study's strategic framework
3. Identify shortcomings with the aid of the case study, literature and consultations
4. Formulate a new strategic framework

Research methodology technological framework

1. Using EDGE, calculate energy and water use, embodied energy, CO_2 for existing technological framework
2. Using EDGE, calculate energy and water use, embodied energy for proposed technological framework
3. Graphically represent the results
4. Compare the results and draw conclusions

.

CHAPTER 4: A CASE STUDY OF KAYAMANDI

4.1. Overview

This chapter presents a case study of Kayamandi, a settlement with informal housing outside Stellenbosch. The case study aims to understand the living situation in Kayamandi with respect to the level of sustainability implemented in the houses, environmental status, governance and social well-being. The purpose of the case study is to examine existing strategic and technological frameworks prescribed for low-cost housing in South Africa. Furthermore, the purpose to is to define and examine shortcomings of the existing framework. This will aid in the formation of a new strategic and technological framework.

This chapter describes the housing conditions, service delivery, technology used to construct low-cost housing (RDP) and general infrastructure of Kayamandi. The strategy the local municipality employs to achieve development and service delivery is also discussed in this case study. Furthermore, this chapter aims to highlight the need for sustainable development and improved frameworks for low-cost housing. More information on the demographic and living status of Kayamandi is available in Appendix B.

4.2. Background to Kayamandi

Kayamandi (meaning ‘nice home’) is a locality situated in the Western Cape, South Africa, on the outskirts of the suburb called Stellenbosch. It was founded in the 1950s and formed part of the segregation under the Apartheid government (Stellenbosch University, 2011).

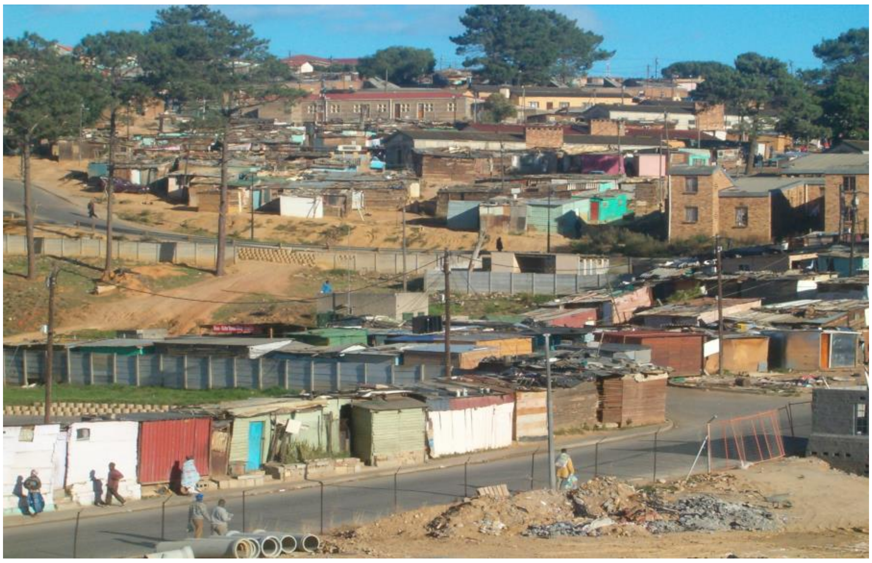

Figure 4.1: Kayamandi (Williams, 2014)

Currently, Kayamandi is a developing ‘township’, with an estimated population of 176 523 inhabitants (Stellenbosch Municipality, 2017). Most of the inhabitants live in underprivileged conditions with regard to social welfare, financial support and ecological security. Figure 4.1 depicts the status of many areas within Kayamandi. From the Figure, it is visible that the standard of living and general community needs improvement.

4.3. Geography and Housing

The total area of Kayamandi is approximately 793.5 km^2, and as of 2011 is occupied by 8 568 households, with an estimated population density of 10 dwellings per km^2 (StatsSA, 2011). In the area, 68.8% of the households are informal dwellings (StatsSA, 2011), with an average of 4.12 people per dwelling (Williams, 2014).

It is estimated that the number of households has risen to approximately 12 000 by 2016, under the assumption that the number grew by 10% per annum (Williams, 2014). Kayamandi is divided into ten different regions, consisting of informal housing, formal housing, traditional housing, prefabricated hostels and brick hostels (Stellenbosch Municipality IDP, 2005:10). Figure 4.2 depicts the informal housing in Kayamandi that numerous inhabitants occupy.

Figure 4.2: Informal Housing (Legacy community development, 2016)

Most inhabitants are unable to afford anything adequate and are forced to build whatever they can to avoid the elements and provide security. Table 4.1 summates the income status of the Kayamandi resident, ranging from ages between 18-65 years old. From the table, it is possible to deduce that a clear majority of the inhabitants struggle to financially support even their basic daily needs. It is possible to assume that the standard of living is less than favourable for most inhabitants. Poverty is a common feature within this settlement as many inhabitants are placed on a waiting list for subsidised housing and are barely able to earn enough income to sustain a satisfactory livelihood.

Table 4.1: Kayamandi Monthly Household Income Status (StatsSA, 2011)

Income	Percentage
R0	29,4%
R1 - R4 800	4,2%
R4 801 - R9 600	5,8%
R9 601 - R19 600	15%
R19 601 - R38 200	23,8%
R38 201 - R76 400	13,4%
R76 401 - R153 800	5,4%
R153 801 - R307 600	1,8%
R307 601 - R614 400	0,8%
R614 001 - R1 228 800	0,1%
R1 228 801 - R2 457 600	0,1%
R2 457 601+	0,1%

Kayamandi has a three-year (occasionally more) waiting list for subsidised housing, with over 20 000 people on the list as of 2014 (Stellenbosch Municipality, 2016). The expansions that are to occur are low-cost housing (i.e. RDP), with 4 600 units planned for 2016 (Stellenbosch Municipality, 2016). The dwellings generally have a total surface area of $36m^2$, with an external slab protrusion of $18m^2$. Furthermore, houses predominantly consist of two bedrooms, a bathroom, a lounge and a kitchen (Stellenbosch Municipality IDP, 2005:12). Figure 4.3 depicts the housing provided to several inhabitants of Kayamandi post 1994.

Figure 4.3: Housing Post 1994 (Legacy Community Development, 2016)

4.4. Living Conditions and Services

The area in which Kayamandi is situated is regarded as a formal space or formal demarcated area or formal settlement. However, the settlement and homesteads are predominantly informal. The living conditions and services linked with informal dwellings are generally neglected. In the case of Kayamandi, the services delivery is above national average for informal housing (Williams, 2014).

Electricity/Energy Supply

The majority of Kayamandi draws electricity from the national grid with most being on a prepaid basis (Darkwa, 2006). Alternate energy forms are primarily consumable resources, with a minor usage of renewable energies (i.e. solar energy). Figure 4.4 depicts the percentage energy sources consumed for cooking, heating and lighting. From the Figure it is clear that the dwellings within Kayamandi use mainly electricity cooking and paraffin for heating and lighting.

Source of Water

According to the Stellenbosch Municipality (2011), potable water for all the regions that fall under their authority is normal. Furthermore, that there was a significant shift from access to potable water outside the dwelling to inside the dwelling. This improved from 71.9% in 2001 to 87% in 2007 (StatsSA, 2011). Since then, the water access in Kayamandi has improved access to potable water to 98.3%, because of the regional water scheme (StatsSA, 2011).

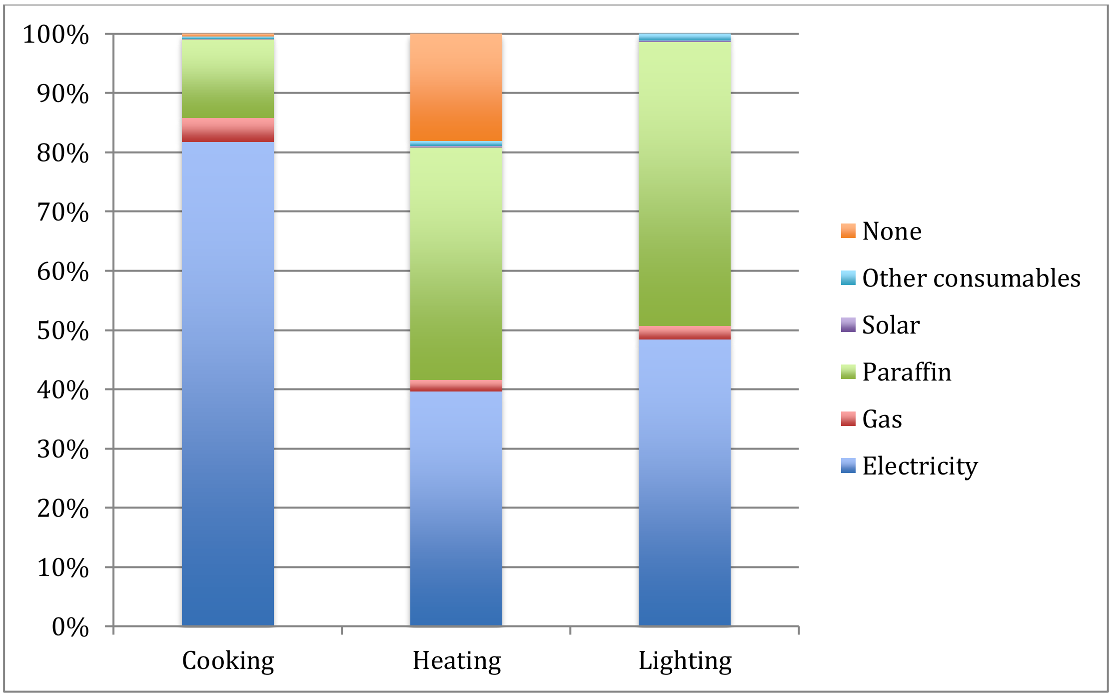

Figure 4.4: Energy Sources Consumed In Kayamandi (StatsSA, 2011)

4.5. Stellenbosch Municipality's Strategic Framework

Stellenbosch Municipality (SM) employs a strategic framework called the Integrated Development Plan (IDP). It aims to develop human settlements and deliver services to Kayamandi and other localities that fall within their jurisdiction. The IDP employs a strategic framework that is coherent with the National and Provincial Housing Legislation. Furthermore, it is used to conceptualise, design, coordinate, manage and facilitate the sustainable development of human settlements (Stellenbosch Municipality, 2014).

The focus of the IDP is to create a nexus between professionals in the public and private sector to provide quality basic services and adequate homesteads. This investigation analyses this strategic framework as it represents the National and Provincial Housing Legislation and is the strategy used to construct low-cost dwellings in Kayamandi. Furthermore, it provides a platform to make relevant sustainable improvements and alterations.

4.5.1. Stellenbosch Municipality Mission Statement

The Integrated Development Plan's (Stellenbosch Municipality IDP, 2005:12) mission is to *"deliver cost-effective services that will provide the most enabling environment for civil and corporate citizens."* To achieve this, they have three core values and five strategies depicted in Figure 4.5. Following is a brief description of the of the three core values upon which they stand:

(1) Character leadership

The Integrated Development Plan (IDP) aims to involve members of the community in the design stages of development in their respective localities, as well as deliver routine status updates on the progress of the performance and implementation of contingency plans for unacceptable service delivery. Finally, status updates about the ineffective management of resources, corruption and fraud that are all hindrances to the integrity of local government.

(2) Transformation

The IDP pursues transformation within settlements and communities through unlocking the potential that the municipality holds. Moreover, they are striving to rectify the economic, social and spatial inequalities caused by historical prejudice.

(3) Innovation

The IDP continually evaluates their systems, methods of practice and processes to enable timeous responsiveness to populace needs, with minimal hindrance from administration. They recognise and provide incentives to initiatives that demonstrate innovation and ingenuity.

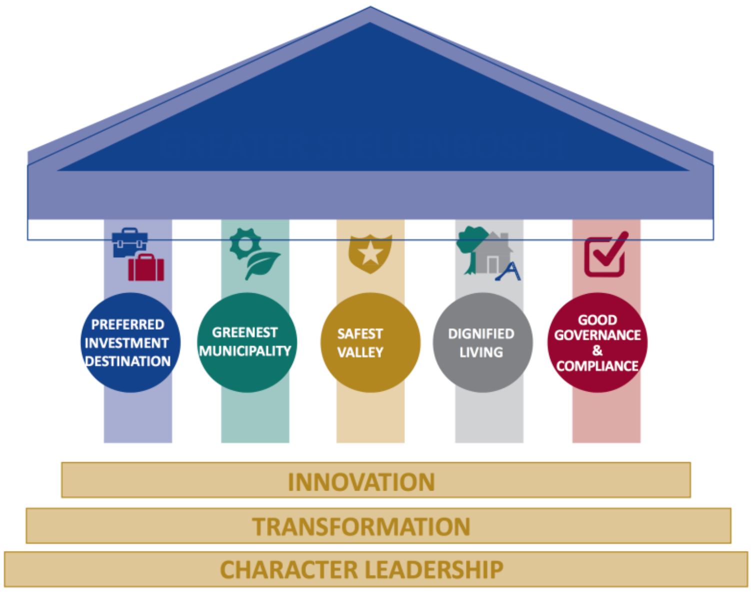

Figure 4.5: Overarching Strategy Of The IDP (Stellenbosch Municipality, 2014)

4.5.2. Strategy Explored

The Integrated Development Plan (IDP) is thus responsible for improving the living standards in localities. Figure 4.5 depicts the overarching strategy of the IDP (Stellenbosch Municipality, 2014). From the figure, it is noted that the IDP wishes to establish safe communities while diminishing the effects of poverty and creating a dignified lifestyle. The strategy also aims to empower the community by creating economic opportunities and involving residents in matters of local government. Moreover, it aims to establish quality and sustainable settlements that should attract investors, like-minded citizens and tourists to the community. Figure 4.5 highlights five key strategic focus areas the Stellenbosch Municipality (SM) employs to achieve a 'greater Stellenbosch'. Following is a brief discussion of all five elements of the overarching strategy (Stellenbosch Municipality, 2014).

(1) Preferred Investment Destination (PID)

The Stellenbosch Municipality (SM) strives to facilitate an environment in which small to large businesses can flourish. The service delivery and infrastructure are targeted at supporting the private sector's initiatives, local government procedure and enterprise progression. The SM employs a Local Economic Development (LED) initiative, which was last updated in 2009. The initiative employed by the SM to facilitate Preferred Investment Destination is as follows:

- Continually improving the LED strategy with close involvement of stakeholders.
- Refining information significant to the LED.
- Facilitating economic prosperity within SM through the support of crucial sectors.
- Ensuring that SM services enable the accomplishment of LED objectives.
- Service organisation, infrastructure development and resource procurement utilise the expertise of the private sector, University and agencies to achieve long-term sustainability.

(2) Greenest Municipality

This strategy aspires to conform to the objectives of the Cape Winelands Biosphere. The Stellenbosch Municipality (SM) wants to create an environment that is clean and respected by the citizens of Kayamandi. The SM aims to rehabilitate the existing environment, plant trees and employ sustainable processes and mechanisms "in its own projects" (Stellenbosch Municipality, 2014). Areas covered in trees should not be used for forestry, but for conservation and recreation.

The SM does recognise that they lack necessary environmental management capacity, air and pollution management and the ability to assess proposals to adhere to the National Environmental Act (Stellenbosch Municipality, 2013). Nevertheless, the 'greenest municipality' focuses on:

- Controlling invasive vegetation on public land.
- Maintain and clean local rivers.

- An eco-centre at Jan Marais Park can be used for environmental education.
- Continue to facilitate urban greening initiatives (i.e. reducing pollution and cleaning the public space).
- Fostering respect for the environment and monuments.
- Support human development.
- Invest in infrastructure and public facilities.

Regarding resource consumption and sustainable development, the Stellenbosch Municipality's strategy is that they *"want to mainstream resource-efficient or green building"* (IDP, 2014). However, the strategy supplies no mechanisms or tangible processes to achieve this objective. According to the IDP (2014), the SM plan to develop the capacity of administrators to encourage green building and their construction development processes are receiving attention to increase efficiency.

(3) Safest Valley

To attain a safe environment the SM strives to ensure that the law is obeyed at all times. Additionally, the SM wants to enforce traffic regulation and to enable effective and timeous response to emergencies. To inaugurate safer regions, SM focuses on traffic, municipal law enforcement, fire control and disaster management.

(4) Dignified Living

The SM recognises that numerous Kayamandi inhabitants do not have access to quality services, housing and public facilities. As a result, they are vulnerable and require aid to support their physical and mental welfare. According to the IDP (2014), remarkable social services are offered by other government organisations, local societies and private agencies. Most of these services rely on the financial resources and management of the SM. The strategy employed by the SM to attain dignified living is:

- Integrating agencies from the public and private sector to ensure the best possible outcome for new developments and upgrades in the informal sector.
- Delivering basic services and housing within the available resources of SM.
- Facilitate the improvement of informal settlements.
- Ensure sustainable management of municipal housing.
- Facilitate the public involvement in community development.
- Ensuring that all inhabitants have easy access to public facilities and services.
- Public facilities are correctly maintained and have competent staffing.

- Ensuring the integrated collaboration and harmonisation of public and private service providers aimed at supporting marginalised groups.

(5) Good governance

Improving understanding of the nature of relationships will better define the services that Stellenbosch Municipality (SM) can provide its inhabitants. The SM also aims to increase to intergovernmental synergy to provide quality basic services, adequate housing and well-maintained public facilities. To achieve 'good governance' the SM employs the following strategy:

- Ensuring that functional areas are prepared to deliver services to accomplish all objectives.
- Presenting opportunities to all members of the SM to assume leadership roles.
- Caring for customers in all aspects.
- Routine performance management of all levels of staff.
- Historical and sensitive manuscripts are correctly maintained.
- Development of centralised and decentralized municipal headquarters to ensure easy municipal interaction.
- Continuation of decision-making structures.
- Engage in sort and long-term strategic planning.
- Establish improved communication corridors between local government and external partners (both local and international).
- Focus objectives of local government and external partners (both local and international).
- Auditing the SM on a regular basis
- Continual efforts to establish a municipal court in Stellenbosch

4.6. Existing Low-Cost Housing Technological Framework

The RDP was commissioned in 1994, with the primary focus to address the socio-economic tension that resulted from the struggle against the Apartheid regime. The programme was additionally aimed at alleviating poverty and to address the absence of social services nationwide. Because the economic and social crisis has yet to be alleviated, the government continually subsidises homesteads for the people living in poverty. According to Statistics South Africa (2016), 53.8 percent of the country is classified as 'living below the breadline'. Therefore, this remains a socio-economic problem in need of immediate relief.

The first RDP that was built was only $16m^2$ and comprised of brick walls with steel cladding for a roof (SAPA, 2008). After regulation was introduced, the total area of the housing was extended to $36m^2$ with the inclusion of an extra front room. The inhabitants primarily relied on fossil fuels (wood, paraffin, candles, etc.) for cooking, heating and lighting. Furthermore, they had to travel, sometimes great distances, with a bucket to the nearest water outlet as access to running water was not introduced into their homes (Danti, 2018).

Although many people still have poor access to services (water, electricity, waste disposal, etc.), regulation is now enforcing that basic human needs be filled within a RDP dwelling and that it needs to be done sustainably. Table 4.2, Table 4.3 and Table 4.4 summarizes the technology implementation proposed by the Stellenbosch Municipality, that are to be taken into to account when constructing low-cost housing (Stellenbosch Municipality, 2014).

In this investigation, certain technological specifications that had no impact on the sustainability of low-cost housing were omitted, that is technologies not considered as sustainable. Table 4.2 focuses on the water guidelines, Table 4.3 focuses on the energy guidelines and Table 4.4 focuses on material guidelines.

Table 4.2: Water Guidelines for Low-Cost Housing (Stellenbosch Sustainability Institute, 2016)

Principle	Technical specification	Exclusions	Preferences
Reduce the use of water as much as possible	All plumbing fittings to be water saving, including aerator taps on all basins, sinks and baths	Non-aerated taps	
Reduce the use of water as much as possible	Low and/or dual flush toilet cisterns and shower heads	Toilet cisterns over 7 litres capacity. More than one bath per house	Showers, sit-baths. Appliances such as washing machines and dishwashers that can be regulated to use minimum water
Recycle Water	Recycling is carried out at a village level. Individual house recycling system will be considered provided it meets safety requirements.		

Table 4.3: Energy Guidelines for Low-Cost Housing (Stellenbosch Sustainability Institute, 2016)

Principle	Technical specification	Exclusions	Preferences
Reduce energy consumption. Diversify energy sources to use most appropriate source	Water heating to be via Solar Panels – electrical or LP gas back- up optional	Stand-alone hot water cylinder. Storage tanks on top of roof	
	Cooking to be by LP gas hob	Electric hobs	LP Gas ovens
	Space heating to be via sunlight and good insulation with minimal electrical or LP Gas back-up		Low wattage space heaters as back-up
Use low energy lighting and electrical appliances	Specify low energy lighting requirements. Also specify low energy requirements when buying electrical appliances etc.		

Table 4.4: Material Guidelines for Low-Cost Housing (Stellenbosch Sustainability Institute,2016)

Materials			
Principle	**Technical specification**	**Exclusions**	**Preferences**
Roofs			
Avoid harmful materials		IBR profile metal sheets, fibre cement sheets or "kliplok" sheets	Natural tiles, concrete tiles or corrugated metal roof sheeting.
Insulation materials		'Think Pink', glass fibre wool, material containing asbestos	Organic materials or safe materials, e.g. cellulose or polyurethane
Lean roofs and Flat slabs			Flat concrete roof slabs are allowed
	Solar panels must be mounted on the roof.		Storage tank not allowed on the roof
Natural lighting	Skylights, dormer lights		
External walls			
Reduce EE		Face brick exposed concrete block work, timber or other panels on street related buildings	Materials to have low EE, manufactured on site and sourced locally
Doors			
Sustainably managed sources.		Winblocks, striped awnings and Meranti wood	Timber or aluminium finishes

It is evident that technological implementations outlined in Table 4.2, Table 4.3 and Table 4.4 have progressed since 1994. The effects of the current framework have had a positive impact on the environment and surrounding communities (Stellenbosch Sustainability Institute, 2014). To better quantify the sustainable impact of the technologies recommended for low-cost housing, they were analysed with the EDGE rating system. Tabulated data and a description of the analysis method are elaborated on in Appendix C.

The analysis of the current technological framework was compared with a 'base case'. To formulate a base case to compare with, numerous assumptions were necessary. The assumptions were based on the literature reviewed in this investigation and provided by the Green Building Council of South Africa. If the information was marginally incorrect, it does not affect the conclusions and recommendations made in Chapter 6.

The base case used in this investigation, are typical households that were erected in Kayamandi by the Stellenbosch Municipality and the Reconstruction and Development Plan. The base case assumptions were primarily on the structure of the building and the materials used to construct dwellings. The building and spatial assumptions of the base case are summarised in Table 4.5.

To use the building-rating tool, mentioned in Chapter 2, numerous assumptions were used, as well as several assumptions recommended by the GBCSA and others gathered from literature and online sources. These assumptions form part of the key energy, water and material analysis performed on the proposed sustainable framework and technologies. Table 4.6 summarises the assumptions.

Table 4.5: Building Area and Spatial Assumptions (EDGE, 2017)

Subject of assumption	Assumption
Average unit area	36m^2
Bedroom area	14m^2
Kitchen area	5m^2
Living/dining room area	10m^2
Bathroom area	7m^2
External wall length	25m
Window to floor ratio*	17% = 6.12m^2 windows
Number of bedrooms	2
Number of occupants	4

*The ratio of total, unobstructed window glass area to total floor area.

Table 4.6: Base Case Operational Assumptions (EDGE, 2017)

Subject of assumption	Assumption
Energy used for water	Electricity
Energy used for space heating (base case)	Paraffin
Energy used for space heating	Electricity
Water consumption	125 L/person/day
Cost of electricity	1.3 Rand/kWh
Cost of paraffin	0.7 Rand/L
Cost of water	30 Rand/kL
CO_2 emissions g/kWh of electricity	870 g/kWh
Window to wall ratio*	15%
Solar reflectivity of wall paint	30%
Solar reflectivity of roof paint	30%
Geyser efficiency	80%
Roof insulation effectiveness (U value)	0.3 W/m^2.k
Wall insulation effectiveness (U value)	0.5 W/m^2.k
Glass insulation effectiveness (U value)	5.8 W/m^2.k
Factor of solar radiation travelling through glass (SHGC)	0.8

*The ratio of total, unobstructed window glass area to total wall area.

Majority of the values are easily altered within the building-rating tool yet remained constant throughout the analysis to properly illustrate the effects of the current and proposed technologies. Further base case assumptions include temperatures, which were not altered by this investigation. These values could easily vary with regard to the size of the structure, quality of materials, consumption rate, etc. Remaining assumptions are mentioned within their specific categories of analysis and results (i.e. energy, water and materials).

The two dwellings (existing technological framework and base case) with their respective technological specifications were analysed using the EDGE building-rating tool. The results for the analysis on the water, energy and material technologies are depicted in Figure 4.6, Figure 4.7 and Figure 4.8 respectively. The figures depict a comparative summation of the calculations that EDGE performs. For example, if a dwelling has low-flow taps in the bathroom and kitchen area, EDGE will calculate the effect the technologies have on the yearly water usage. The reduction of water use is then displayed using a stacked bar graph and compared to the base case.

It should be noted that specific assumptions for the base case had to be made in order to effectively illustrate the effect the technologies would have on a dwelling. Assumptions include water and energy consumption per annum and embodied energy per metre squared. Realistic values may vary depending on inhabitant's consumption, geography, number of inhabitants, etc., and the assumptions made are representative of the case study. Furthermore, the results are indicative in that it illustrates the effect of technologies after they were implemented.

It should be noted that some technologies have the ability to affect more than one criterion. For example, using a low-flow showerhead will have a direct effect on the amount of water is used and will have an indirect effect on the amount of energy consumed because there is less water to heat up after shower usage. When analysing technologies, this investigation did not account for the indirect effects as it was (1) difficult to accurately quantify, (2) presenting the effects in isolation would better illustrate the implications of technologies and (3) the indirect effects were much less compare to the direct effects.

Figure 4.6 represents the water savings that were incurred for a year by implementing the existing low-cost housing technologies. The base case consumed approximately 181 kilolitres of water per year, whereas the improved case (existing technological framework) consumed approximately 151 kilolitres (kL) of water per year. Saving a total of 30 kL per annum, which comprises of 7 kL from the shower, 9 kL from water faucets and 14 kL from the water closet. Thus, the water savings of the current technologies is rated at approximately 16.6%.

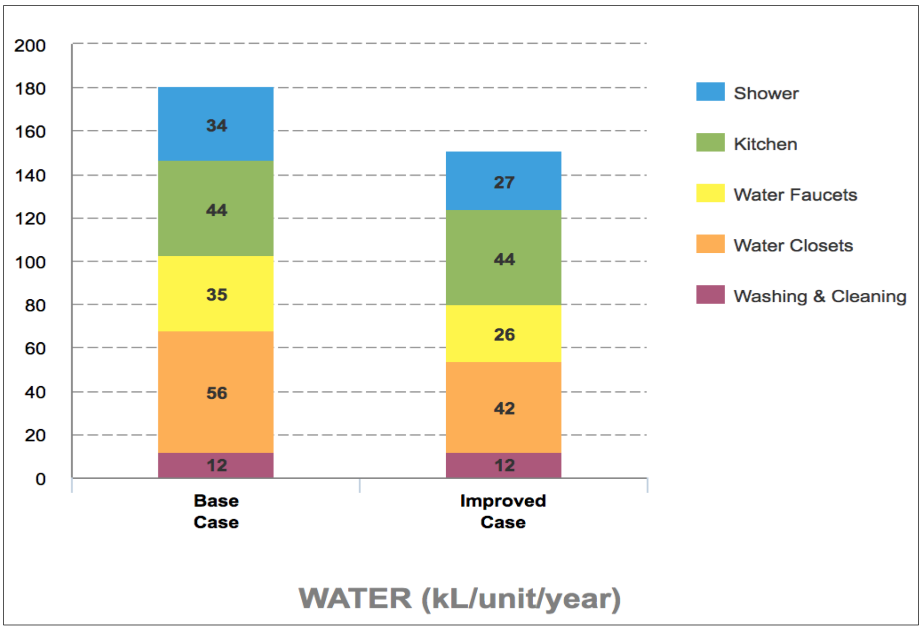

Figure 4.6: Current Framework's Water Performance

Figure 4.7 represents the energy savings that were incurred for a year by implementing the existing low-cost housing technologies. The base case consumed approximately 94 kilowatt-hour per metre squared of energy per annum (kWh/m^2/Year), whereas the improved case (existing framework) consumed approximately 78 kWh/m^2/Year. Saving a total of 16 kWh/m^2/Year, which comprises of approximately 1 kWh/m^2/Year from heating energy, 10 kWh/m^2/Year from cooling energy, 1 kWh/m^2/Year from fan energy, 1 kWh/m^2/Year from lighting energy and 3 kWh/m^2/Year from hot water energy. Thus, the energy savings of the current technologies is rated at approximately 16.12%.

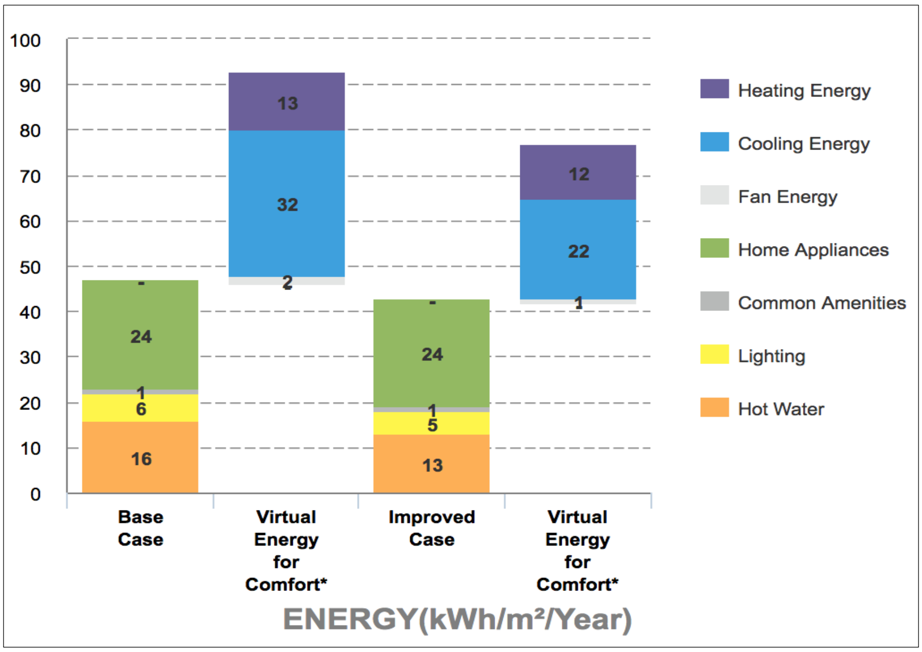

Figure 4.7: Current Framework's Energy Performance

Figure 4.8 represents the embodied energy savings that were incurred by implementing the existing low-cost housing technologies. The base case consumed approximately 6080 Megajoules per metre squared (MJ/m^2) of energy, whereas the improved case (existing framework) consumed approximately 5597 MJ/m^2. Saving a total of 483 MJ/m^2, which comprises of 214 MJ/m^2 from roof construction, 56 MJ/m^2 from flooring and 213 MJ/m^2 from windows. Thus, the energy savings of the current technologies is rated at approximately 7.93%.

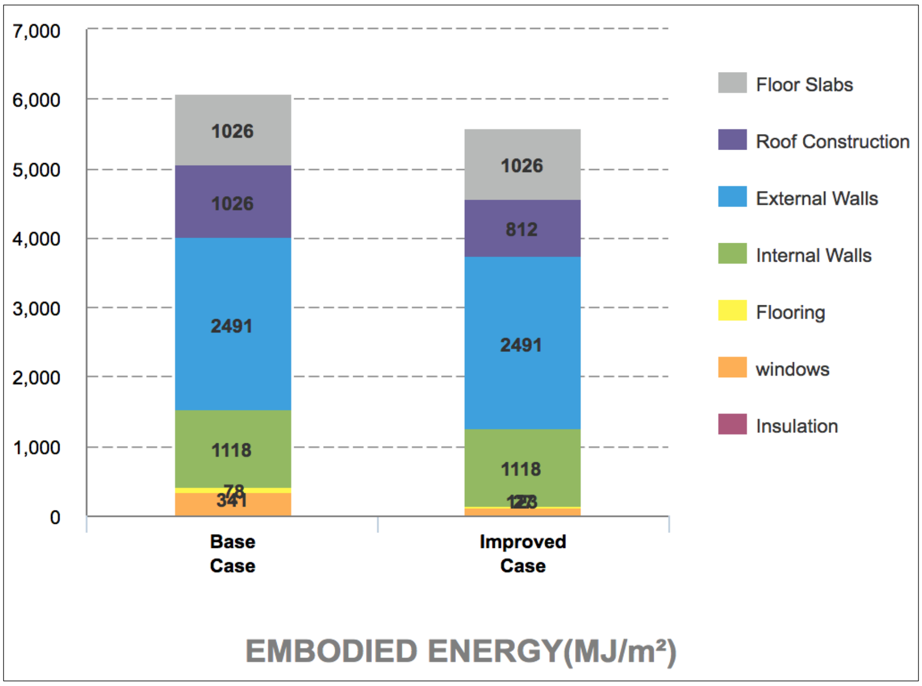

Figure 4.8: Current Framework's Embodied Energy Performance

The results show a definite reduction in energy (direct and embodied) and water consumption. According to the EDGE certification, a building should receive a sustainable 'increase' of 20 percent in every field (EDGE, 2017). The house's technological framework does not meet the requirements set out by the Green Building Council of South Africa. It should be noted that the technologies perform commendably and provide a substantial level of sustainability. However, even the same performance could be achieved at a fraction of the cost with newer technologies. This is will be made apparent in Chapter 5.

The EDGE rating also highlighted that a minor reduction in operating CO_2 emissions. As mentioned in Chapter 1, the construction industry accounts for a third of global green house gas (GHG) emissions. With the increasing threat of global warming, Green House Gasses mitigation is tremendously important. Therefore, the existing low-cost housing framework in Kayamandi will need to further reduce the operational CO_2.

As mentioned in Chapter 1, available technologies can reduce a building's energy consumption by 30-50 percent. While the type of technology available might be infeasible for subsidised housing, reaching the 30-percentile range should be easily achievable with the current resources and economic standing of South Africa. It should also be noted that the framework does not mention the demolition phase of a building. From Section 2.9, it is evident that it contributes to the Life Cycle Energy. Although the EDGE tool does not take the demolition phase into account, it would nevertheless increase the sustainability of the framework.

The lack of sustainable performance of the low-cost housing framework could be accounted to numerous aspects, including lack of enablers, technology diffusion techniques, government policy, neglect, social acceptance, etc. This highlights that the existing framework is not operating efficiently and will not support a sustainable future. Therefore, the current framework will need to be upgraded to reduce the biospherical impact of low-cost housing.

The current framework in Kayamandi and the RDP is a valuable addition to frameworks applied to settlements, as it allows for sustainable systems to be added to the constructs. The framework is necessary in providing dwellings for the people on subsidy waiting lists, yet in terms of sustainability, it could be improved. Although additional technologies would increase the overall cost slightly, it would greatly improve the overall quality and sustainability of a settlement.

4.7. Conclusion

The case study has highlighted numerous aspects that need attention to transform Kayamandi into a sustainable settlement. Firstly, there is a desperate need for subsidised housing in Kayamandi as the waiting list is incredibly large. There are numerous citizens that have waited more than three years for their basic needs to be fulfilled. From this chapter, it is visible that a clear majority do not earn enough income to sustain themselves, let alone afford a dwelling.

It is the inhabitants' Constitutional right to be provided with adequate homesteads and basic service delivery. With the enormous amounts of backlogs, it consequently presents an opportunity for future developments to be sustainable. Furthermore, the developments have the potential to be primarily sustainable with respect to services and housing.

Secondly, after reviewing the greenest municipality strategy, a miscommunication in terminology has been identified. Where normally 'green' is generally associated with conservative resource consumptions and long-term environmental sustainability, the Stellenbosch Municipality's definition mainly focuses on the tree planting, cleanliness and pollution of localities. While, this is necessary for the environment and forms an integral part of 'green', the strategy does not engage many of the principles of sustainability. Moreover, the strategy has little indication of linking the informal economy with the green economy in

Kayamandi. Engaging in this should act as an enabler to increase the sustainability within the settlement through community participation.

Finally, a large portion of the energy currently consumed in Kayamandi is fossil fuels (paraffin). As mentioned in Chapter 1, the contribution of fossil fuels to global CO_2 levels and to negative impact on the environment is immense. It is necessary for settlements to diverge from using fossil fuels as their primary means of energy. Applying sustainable technologies to new and existing dwellings will mitigate majority of the consumption of fossil fuel.

This case study provided an example of existing strategic and technological frameworks prescribed for low-cost housing, both of which are prescribed by the Stellenbosch Municipality. Thus providing a platform to review the current technological and strategic frameworks in South Africa. This subsequently aided in the formation of a new strategic and technological framework.

With respect to other settlements in South Africa, Kayamandi is in a relatively good condition, with sufficient basic services. Nationally there is a large backlog in delivering low-cost housing (RDP) and as the case study would suggest, there is little sustainable technology or principles applied to existing or new developments. This chapter highlights a need for innovations in settlements and change in policy.

CHAPTER 5: RESULTS AND DISCUSSION

5.1. Overview

This chapter presents the results of the analysis on the case study and the proposed framework from data collected from StatsSA, Green Building Council of South Africa (i.e. EDGE software) and Stellenbosch Municipality. The purpose of this chapter is to demonstrate the relevance, applicability and level of sustainability of the new framework. Furthermore, it aims to provide validation by presenting the results graphically.

To sufficiently illustrate the analysis, the technological framework from the case study was compared graphically to this investigation's proposed technological framework. Additionally, this chapter proposes alterations to the strategy discussed in Chapter 4, and presents a strategy map depicting the proposed strategic framework.

In order to conduct a thorough analysis, certain assumptions had to be made, which were presented by Table 4.5 and Table 4.6. The assumptions include spatial and operating parameters of the dwelling under consideration. After the proposed framework and results are presented, the conclusions and recommendations aim to achieve a higher level of sustainability in settlements.

5.2. Proposed Framework

Chapter 4 conducted a review of the strategic and technological framework employed by the Stellenbosch Municipality to facilitate sustainable development in settlements. The review identified numerous aspects of the framework that were possibly shortcoming to fully achieve maximum sustainability within Kayamandi and South Africa. Following in Section 5.2.1 is the proposed strategic framework and in Section 5.2.2 is the proposed technological framework.

5.2.1. Proposed Strategic Framework

Chapter 4 conducted a review of the strategy employed by the Stellenbosch Municipality to facilitate development in human settlements. The review identified numerous aspects of the strategy that were possibly shortcoming to fully achieve maximum sustainability within Kayamandi and South Africa.

As the policy and strategy review (Appendix A) suggests, there was no tangible evidence that suggests that roles and responsibilities of the Stellenbosch Municipality (SM) officials were properly defined. Furthermore, there are no practical mechanisms to help officials achieve the goals set out by the SM. It would be difficult to assume a role within government and not know the function and purpose of that role. – Thus, there is a need for proper allocation of objectives coupled with an effective method to achieve objectives.

If responsibilities were not properly defined and accompanied with mechanisms, it is unlikely that objectives would be achieved to their full potential. This is assumed, as there is much confusion with terminology and a need to 'develop the capacity of administrators to encourage green building'. Furthermore, the green strategy of the municipality only suggests a reduction in pollution and deforestation; this suggests a misconception of terminology of the principles of sustainable development. – Thus, it is necessary to better define terminology and sustainable principles and practices.

The green strategy of SM mentions that they "want to mainstream resource-efficient or green buildings" (Stellenbosch Municipality, 2014). This would suggest that the SM does not implement the available green technologies to their fullest potential. Furthermore, the current developments are not resource-efficient or green constructs. There are numerous sustainable technology providers in the public sector that SM could partner with, to increase the level of sustainability in settlements. This highlights a need for assistance from private sector or institutions (e.g. Green Building Council of South Africa) to introduce technologies into the developments and form partnerships with such establishments. – Thus, there is need for more synergy with the private sector ('green partnerships') to effectively mainstream green technology implementation.

It is recognised that there is community involvement with a large portion of the public sector. However, there has been minimal effort to include the students at Stellenbosch University to support sustainable development or green economic activity. Most of this responsibility falls upon Non-governmental organizations and the private sector. – Thus, create a channel for volunteering and university involvement. This will enable innovations to be filtered up from the students and lecturers. .

As mentioned in Chapter 1, there are many economic opportunities and green technologies that can be created from 'bottom-up' innovation within settlements. Furthermore, it is likely to create a link between the informal economy and the green economy. Creating a market for inhabitants to distribute green products and green services would promote a linkage between the informal economy and green economy. – Thus, promote green innovations within settlements, which will in turn create linkages to the informal economy.

The core values of the Stellenbosch Municipality (SM) state that there are incentives for inhabitants that 'demonstrate innovation' (Stellenbosch Municipality, 2014). This did not form part of the strategies proposed by the SM; the strategy could either include an incentive program and/or a disincentive initiative. Incentives could be rewarded to inhabitants that partake in installing sustainable technologies and practicing sustainability principles. It will benefit the inhabitant and relieve strain felt on the resources of South Africa.

Alternatively, if the inhabitants of a dwelling do not partake in sustainable practices, there could be an enforcement of a penalty fee or increase in utilities. However, this is unlikely to be successful for recipients of low-cost housing, as they do not construct their own homes.

While reviewing the good governance strategy it was noted that the SM does not place pressure on policy makers to enable change within national and local housing strategies. With added pressure from local institutions and public communities, the local policies could enable more sustainable developments in settlements. This strategy will take a considerable amount of community engagement and participation, which can be time-consuming. Nevertheless, it should have an incremental effect on the overall sustainability over time. – Thus, with the correct pressure from public and private sector, local policies could be altered to increase green participation.

It was noted by the SM that the Preferred Investment Destination (PID) strategy was last updated in 2009. While the objectives of the strategy are coherent with facilitating sustainable development, it is doubtful that the practical mechanisms to achieve the strategy's objectives are currently relevant. Additionally, since 2009 there were numerous incidences that could negatively affect investor confidence.

In addition, the SM noted that the PID is targeted at the 'private sector's initiatives, local government procedure and enterprise progression'. It can thus be assumed that the strategy does not include channelling investments to informal economy or green economy development. Doing so should enable 'small to large businesses to flourish' within informal settlement (Stellenbosch Municipality, 2014). – Thus, channel partial investments into informal and green economic activities.

Hindering the Stellenbosch Municipality (SM) to achieve a green municipality (correctly defined 'green' in this case) is a 'lack of capacity to assess proposals'. It is noted that proposals made to the SM do not have clear objectives and are not in the confines of available resources. Therefore, solutions could include an increase in the capacity of SM, for proposals to be easily assessable. Alternatively, the SM should engage with the proposers to enable easier assessments. The most effective method would be a combination of the two solutions. - Thus, the SM should request easily assessable proposals or increase capacity.

From the analysis, it is noted that issues surrounding the strategic framework of the case study are predominantly resulting from a lack of drivers, mechanisms and performance measures. Moreover, this investigation noted numerous other issues from the literature and consultations that fall within the same scope. These combined issues have highlighted a need for the following:

Drivers

- People with relevant experience and capacity to develop a sustainable policy
- A prescribed approach to prevent environmental and spatial limits from being reached
- A body to represent the people within a locality to define and express their needs (social and economic) to local municipalities
- More pressure on policy makers and stakeholders to facilitate sustainability
- A channel for drivers to reach mechanisms

Mechanisms

- More engagement with technological innovations
- Align more private and public investments with the development of settlements
- More interaction with stakeholders to create system and strategic enablers
- The creation of more initiatives to link the green economy to the informal economy
- To increase and introduce partnerships that enable sustainable construction

Performance Measures

- Long-term indicators to measure the progress of the strategies
- Feedback from the people within the developments to understand the effect of the strategic framework
- Apply indicators and benchmarks to measures whether the technologies are performing

To facilitate sustainable development, this investigation proposes a strategic framework to address these three core issues as mentioned above. The drivers, mechanisms and performance measures are illustrated in Table 5.1, Table 5.2 and Table 5.3 respectively. Each main issue is further scrutinized with actionable applications to facilitate a sustainable strategic framework.

Table 5.1: Proposed Strategic Framework's Drivers

Drivers	
Social and economic needs	- Strengthen the regulatory capacity of government - Increasing the effectiveness of standards initiatives led by private and public actors. - Enhancing grievance procedures. - Monitoring of social and economic impacts. - Reinforcing the role of international law and intergovernmental processes in standards governing investors and enterprises.
Environmental limits	- Promote better products and services, which have lower environmental impacts - Dissociate economic growth from environmental degradation. - Integrate the management of land, water and natural and renewable resources
Policy and institutional pressures	- Improve the capacity for policy integration at all levels of government - Ensuring key economic, environmental and social considerations are integrated into policy - Provide incentives to innovate and diffuse technologies that support sustainable development - • Strengthen synergy among stakeholder, investment, environmental, and social policies

Table 5.2: Proposed Strategic Framework's Mechanisms

Mechanisms	
System and strategic enablers	- Create a database of systems that incorporate sustainable practices to compare their effectiveness on varying climates - Formulate a communication channel to facilitate increased stakeholder involvement in technology creation and diffusion - Incorporate the public and private sector when creating strategies
Technological innovations	- Develop a life cycle performance database for existing technologies that use local benchmarks - Promote local technology creation and technology transfer from developed countries - Create an inventory of design, assessment and building-rating tools appropriate for South Africa
Stakeholder and investor action	- Conducts research to provide data and insights on returns on investments - Provide access to a global organizations interested in diversifying their portfolios with the investment in technologies - Provide tools, guidance, training, and resources to help investors identify metrics and integrate them into investment options

Table 5.3: Proposed Strategic Framework's Performance Measures

Performance measures	
Community feedback	- Create system to log community feedback with proposed solution to monitor future impact and effectiveness - Engage with community to incorporate social, economic and environmental needs into mechanisms - Establish channels for innovations to be filtered from bottom up.
Measurement indicators	- Develop indicators to measure economic, environmental and social performance of sustainable cycle - Incorporate results gained from indicators with mechanisms to continually improve sustainable practices - Create benchmark using indicators for new innovations to improve on

This tables highlight that three key drivers to enable sustainable development are environmental limits, social and economic needs, and policy and institutional pressures. These drivers facilitate the mechanisms of sustainable development, which is system and strategic enablers, technological innovations and stakeholder and investor action. The mechanisms are reliant on each other and create a cycle of sustainable development. Once the cycle is operating, it is intended to further synergise with interaction between the mechanisms.

When the necessary investments (resources, etc.) and innovations meet the requirements of the strategy, they can be implemented to develop or refurbish sustainable settlements. To ensure long-term and strong sustainability, achievement measurement indicators and feedback from the community is necessary. This information is returned into the synergy cycle to enhance the process and improve sustainability. The relationship between the drivers, mechanisms and performance measures (Table 5.1, Table 5.3 and Table 5.3 respectively) is depicted in Figure 5.1 and forms a map for the proposed strategic framework.

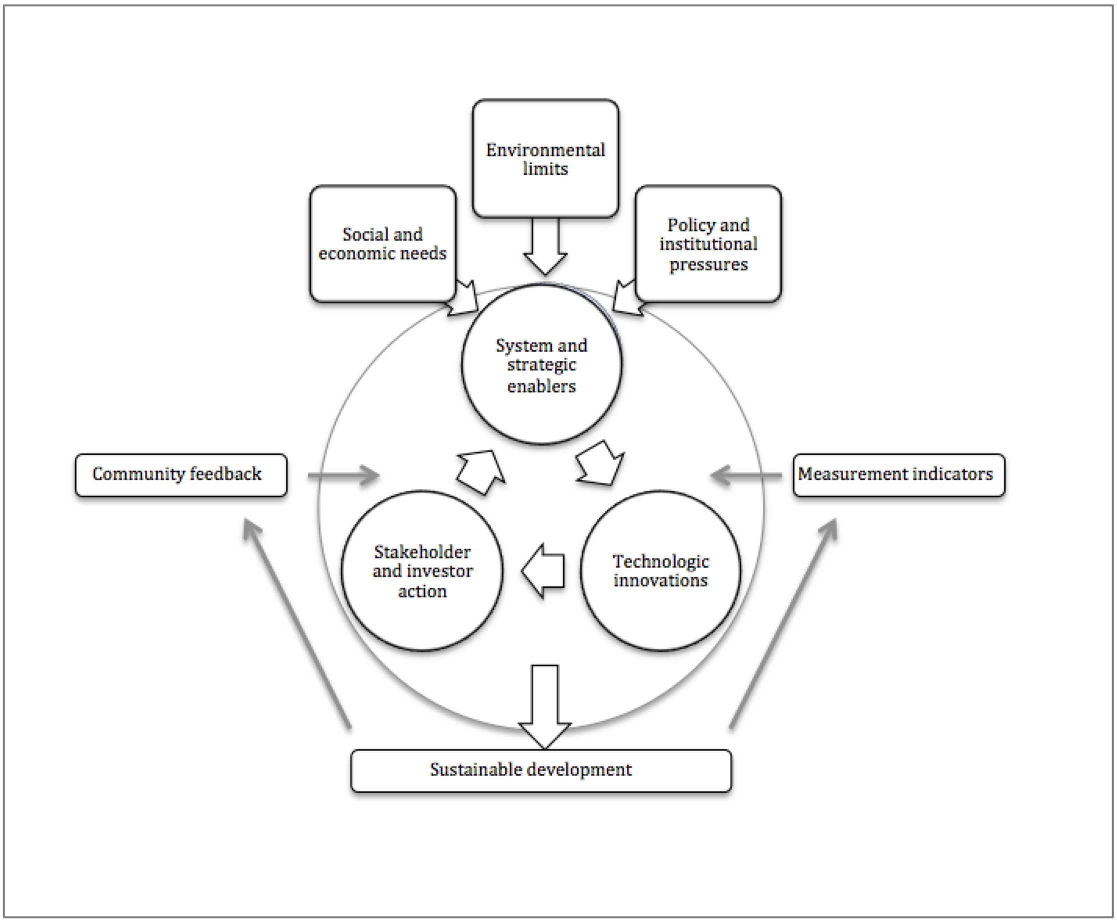

Figure 5.1: Proposed Strategic Framework Map

5.2.2. Proposed Technological Framework

For the proposed technological framework, numerous aspects were taken into account when selecting technologies to analyse. The chief aspects were the cost of the technologies and the availability of the technologies in South Africa. The reason cost was considered is that many highly efficient technologies available are too expensive to be implemented into low-cost housing. Furthermore, it would decrease the amount of houses built, as the government's budget is limited.

The focus of the technological framework was to keep the cost low, have a fast payback period and improve the level of sustainability to be acceptable by the Green Building Council of South Africa. Following are the guidelines of the proposed technological framework, illustrated in Table 5.4, Table 5.5 and Table 5.6.

The technologies and guidelines selected by this investigation were based on the recommendations of an organisation called My Green Home (My Green Home, 2017). The My Green Home campaign was created and is managed by the Green Building Council South

Africa. They are a non-profit organisation that advocates and encourages green building practices in the South African commercial and residential property sector. Furthermore, they recommend technologies for dwellings and provide guidance for people or organisations wanting to construct a sustainable dwelling. The technologies selected were specifically recommended for low-cost housing, as they are efficient and easily implementable on a large scale.

Table 5.4 summarises the water guidelines and principles of the proposed technological framework. These principles were considered and adhered to when selecting technologies and conducting the analysis.

Table 5.4: Proposed Framework's Water Guidelines and Principles

Classification	Technical Specification	Exclusions	Preferences or Recommendations
Reduce water in water closets	Water to be replaced with grey water or rain harvester		Packets with pebbles, filled water bottles in water closet.
Reduce water in bathrooms	Water closet to be replaced with single or dual flush system. Regulated toilet flapper to reduce amount per flush.	Water closets more than 8 litres per flush.	Dual water closet with 3 litres per flush.
Faucets and sinks	Low-flow aerator in bathroom sinks, swivelling aerator in kitchen sinks.	Non-aerated taps.	High efficiency dishwasher saves more than hand washing.
Shower heads	Low-flow shower heads 8 l/min or below	More than one bath in the dwelling.	Sit baths used for small children.
Gardening	Grey water to be used for gardening	Hose pipes with open ends.	

Table 5.5 summarises the energy guidelines and principles of the proposed technological framework. These principles were considered and adhered to when selecting technologies and conducting the analysis.

Table 5.5: Proposed Framework's Energy Guidelines and Principles

Classification	Technical specification	Exclusions	Preferences or Recommendations
Geysers	Hot Water Collectors to replace 70% of annual water heating demand.	Fires to heat up water.	
Heating	High Efficiency Boilers for space heating	Electric glow coil heaters	Electric stove that has heating function.
Natural ventilation	Areas to be designed to maximise air flow throughout dwelling.	Large floor to ceiling windows reduce insulation.	More frequent windows than one large one.
Reduced window to wall ratio	9% ratio to reduce energy flow through windows.	Large floor to ceiling windows reduce insulation.	
Windows	Low-E coated glass windows - U Value of 3 W/m^2 K and SHGC of 0.45		Double pane windows
Energy efficient bulbs	Compact fluorescent lamp (CFL) or light emitting diode (LED) bulbs.	Incandescent light bulbs.	LED light bulbs last longer and are more efficient.
Energy efficient appliances	Fridges, tumble dyers, washing machines, dishwashers, etc. to have South African Energy Efficiency Label		Solar powered fridges. Do not leave desktop computers on stand-by.

Table 5.6 summarises the material guidelines and principles of the proposed technological framework. These principles were considered and adhered to when selecting technologies and conducting the analysis.

Table 5.6: Proposed Framework's Water Guidelines and Principles

Materials			
Classification	**Technical specification**	**Exclusions**	**Preferences or Recommendations**
Roof			
Use recycled materials	Use materials that do not influence insulation.	Metal sheeting, untreated timber. Any material with asbestos.	Natural materials or recycled synthetic materials.
Insulation materials	Use cellulose or polystyrene	'Think Pink', glass fibre wool, material containing asbestos.	Polyurethane also acceptable.
External Roofs	Support structure made of timber with asphalt shingles or corrugated metal roof sheeting.	Concrete roof slabs. Avoid metal sheeting for insulation.	Clay roofs or micro-concrete tiles also acceptable.
Solar Equipment	Solar photovoltaics and hot water collectors to be on roof facing North	No generators or water storage units on roof.	Solar power packs can be placed indoors to store energy for the evening.
Natural lighting	Small centrally placed windows in living room.	Large openings decrease insulation	Low-E coated glass windows
External and Internal Walls			
Reduce embodied energy	Rammed earth wall or compressed stabilised earth blocks.	Common clay bricks plastered on both sides. Metal sheeting. Timber boards.	Natural materials or recycled materials.
Insulation	Polystyrene placed in wall cavity	Woodwool, 'Think Pink' or any materials containing asbestos	Spray Foam also acceptable.
Floors			
Surface bed	Use Power Float of concrete to act as finished floor	Laminated wood floors. Nylon carpets. Terracotta tiles	Depending on availability use cork tiles and plant fibre flooring.
Floor slab	Timber to be used for any additional raised areas.	Concrete floor slabs.	
Doors and Window Frames			
High durable timber	Timber to be sustainably sourced	Untreated wood Plastics such as PVC-U	Aluminium also acceptable.

5.3. Results

Section 5.4 presents the results of the analysis of technologies and materials that form part of the proposed framework of this investigation. The My Green Home recommended the technologies analysed by this investigation (My Green Home, 2017), by providing the most efficient and easily available technologies in South Africa. The tabulated results and details of all the energy, water and material technologies can be viewed in Addendum D. The technologies were inserted and analysed individually using the Edge building-rating tool and the respective results and calculations are tabulated in Addendum D. The aspects that were analysed with respect to energy and water are listed as follows:

- Additional cost of technology (ZAR/unit): the added cost to install the technologies into already existing or newly developed dwellings.
- Direct utility costs reduction (ZAR/ month): the direct cost savings of the technology on the utility bill issued for public services.
- Total utility cost (ZAR/ month): total direct utility cost per month after technology installation.
- Operational CO_2 mitigation (tCO_2/year): total yearly carbon dioxide emission reduction.
- Years till technology pays itself off (year): indirect savings made on reduction of energy and water needs.
- Electricity use (kWh/month): Total electricity use of dwelling per month.
- Energy or water savings (%): the total amount of energy/water saved as a percentage of base case energy consumption.
- Water use (L/month/unit): new monthly water consumption per dwelling.

The results obtained from the energy and water analysis were ranked using a performance ratio or the 'effectiveness ratio'. This ratio represents the additional cost of technology divided by the amount of energy or water savings percentage (ZAR/%). Essentially, it indicates how much money is being spent per percentage of savings received.

The technologies, now ranked by performance, were graphically represented. The results from the case study and this investigations framework were represented on the same axis. The energy and water analysis of the base case represents a zero value (i.e. x = 0 and y = 0) on the same axis.

Occasionally there were clashing energy and water technologies. This means that two similar technologies were not included in this investigation's proposed framework, as they would have related or the similar functions and thus be a waste of resources. For example, installing a dual flush water closet and a single flush water closet in the same bathroom would be unnecessary, as its only possible to fit in one water closet in each bathroom. Therefore, the technologies that clashed, only the best performing were implemented and the others discarded.

Each technology recommended by the GBCSA was analysed separately in the building-rating tool to understand and quantify the effectiveness of individual technologies. This reason for individual analysis is that performances of multiple technologies 'stack'. Therefore, it would be difficult to separate their contribution to overall sustainability.

There were certain technologies that were not analysed at all, as they were too expensive, encompassing, presented safety issues or were inefficient. For example, using fossil fuels for space heating was not included because it is a safety hazard and contributes significantly to CO_2 emissions. Tabulated results of all the analysed technologies can be found in Appendix D.

Building elements were separated into categories, to facilitate an easier examination of the materials. The dwellings were divided into floor foundation, roofing, external wall, internal wall, flooring, window frames, roof insulation and wall insulation. The aspects that were analysed with respect to building materials are listed as follows:

- Additional cost reduction (Rand/unit): indirect cost savings resulting from using 'greener' materials.
- Embodied energy savings (Megajoules): the total energy saved through the life cycle of the materials.
- Indirect electricity savings (kilowatt hour): indirect electricity savings resulting from reducing material energies.
- Material savings (%): the total amount of materials saved as a percentage of base case material use.

The material analysis was conducted differently to the energy and water analysis. This is to be expected, as the materials do not contribute as significantly to electricity and water savings. Additionally, it would be difficult to project a year until the technology pays itself off because it does not reduce utility cost and thus does not save the inhabitants money. Additionally, material prices vary depending on material availability and nearby recycled materials. For example, it would still be more cost effective to reuse recycled materials with a high-embodied energy, than buy materials with a low embodied energy. Therefore, the analysis merely represents the embodied energy of all the materials and indirect costs that are associated with it. That is, the equivalent electricity and money savings corresponding to embodied energy savings.

5.3.1. Energy Results

After the technologies were ranked using the effectiveness ratio, the results were cumulated and graphed. The results from the existing and proposed framework are presented graphically to illustrate the need for increased sustainability. Furthermore, it illustrates that a higher sustainability is attainable at a lower cost. Figure 5.2 represents the relationship between cumulative energy savings and cumulative cost; the green line represents the acceptable level of energy savings by the Green Building Council of South Africa (GBCSA), which is 20%.

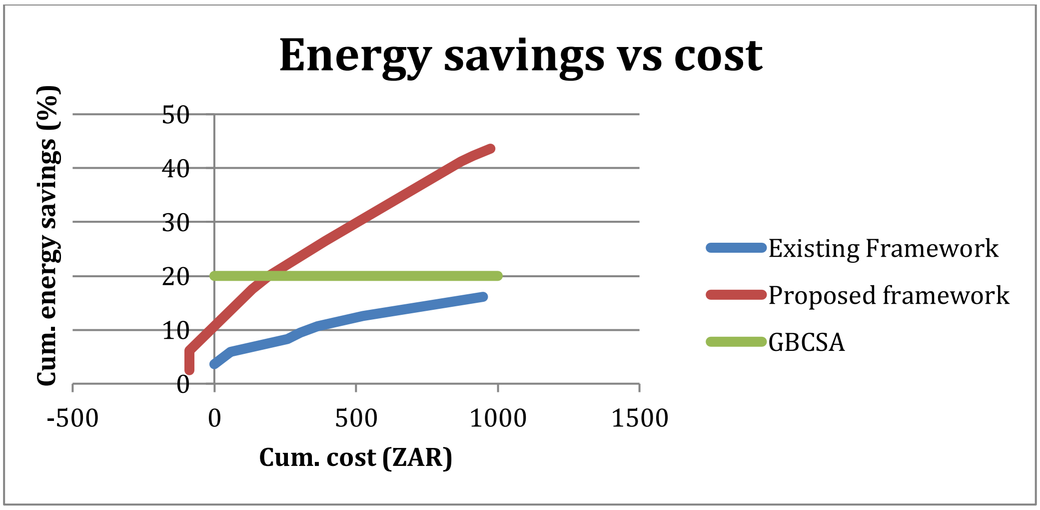

Figure 5.2: Energy Savings vs. Cost

Figure 5.2 is a good depiction of investing finances in the correct technologies, as the result is more effective energy savings. From the figure it is noted that the proposed framework reaches the GBCSA required 20%, around a cum. cost of R150, whereas the Stellenbosch Municipality (existing) framework spends nearly R950 and does not reach it.

Figure 5.3 represents the relationship between cumulative utility reduction and cumulative cost. The figure illustrates that with similar cost of technologies, the proposed framework can reduce the monthly utility cost to R51.87 as opposed to R12.24. This will take the strain off the low-income received by the majority of inhabitants in Kayamandi.

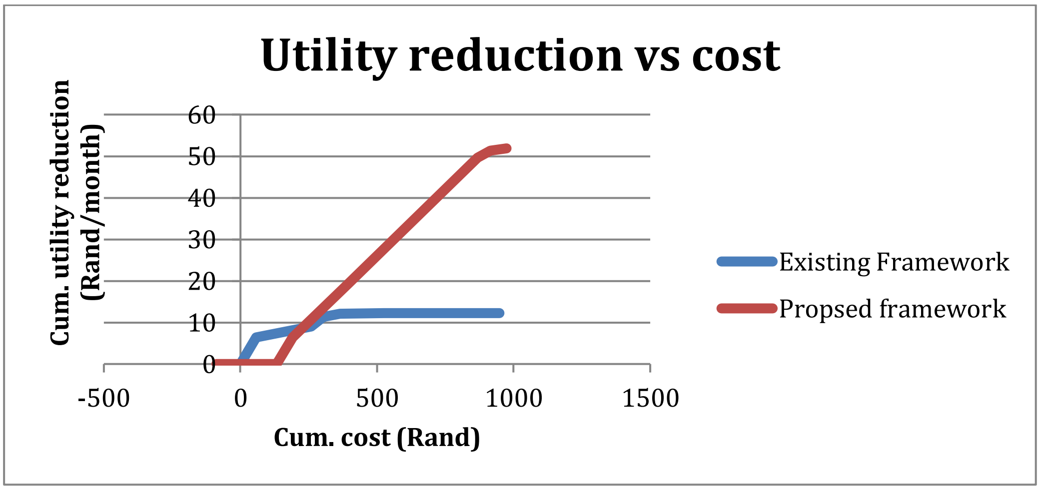

Figure 5.3: Utility Reduction vs. Cost

Figure 5.4 represents the relationship between cumulative years till the technology pays itself back versus cumulative cost. The results of this figure represent the total time that it would take the installed technologies to start being beneficial. It is visible that the proposed technologies will be beneficial sooner.

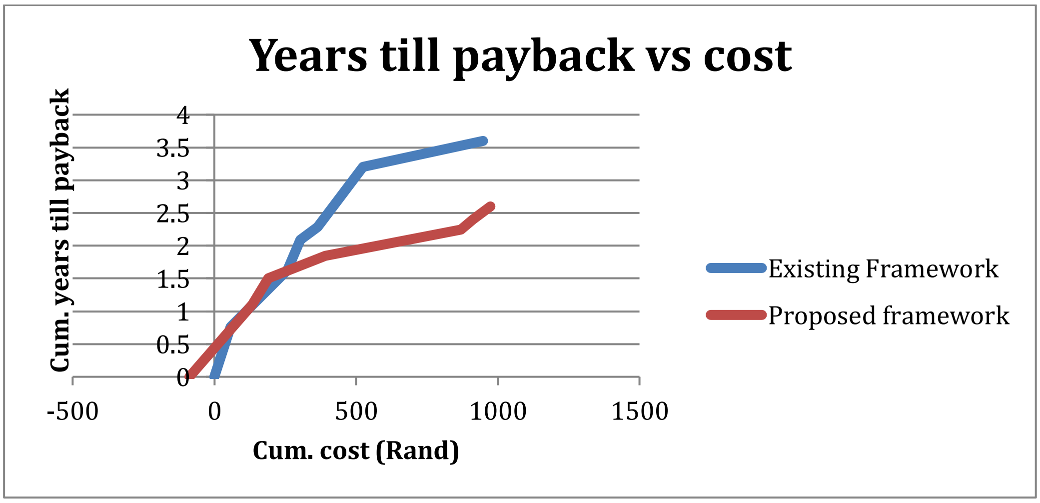

Figure 5.4: Years till Payback vs. Cost

Figure 5.5 represents the relationship between cumulative final monthly energy usage and cumulative cost. The figure represents the reduction to the total electricity consumption per month. The results show a R36.7 difference between the two frameworks.

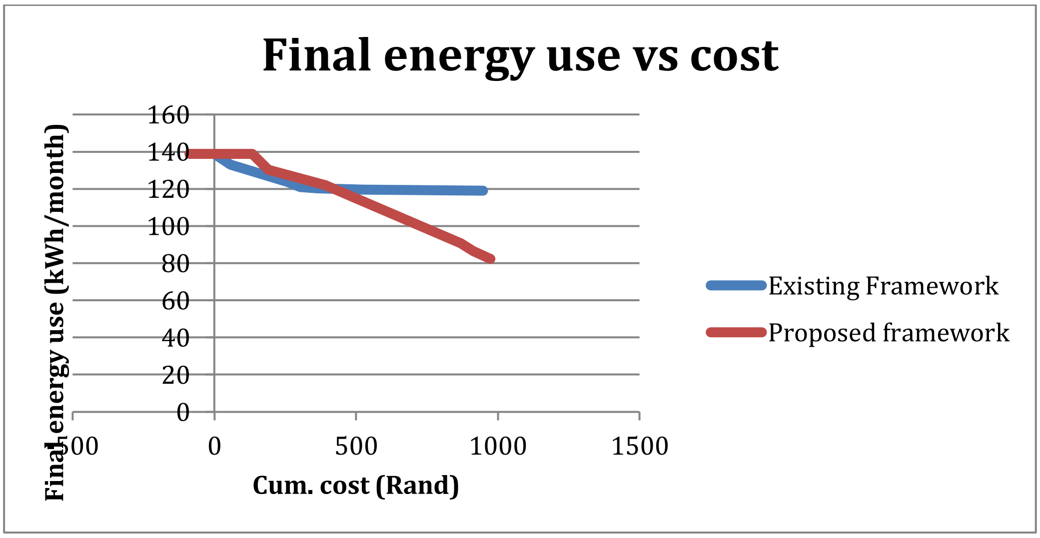

Figure 5.5: Final Energy vs. Cost

Figure 5.6 represents the relationship between cumulative operational CO_2 mitigation and cumulative cost. The results highlight significant differences in annual carbon emission mitigation between the two frameworks.

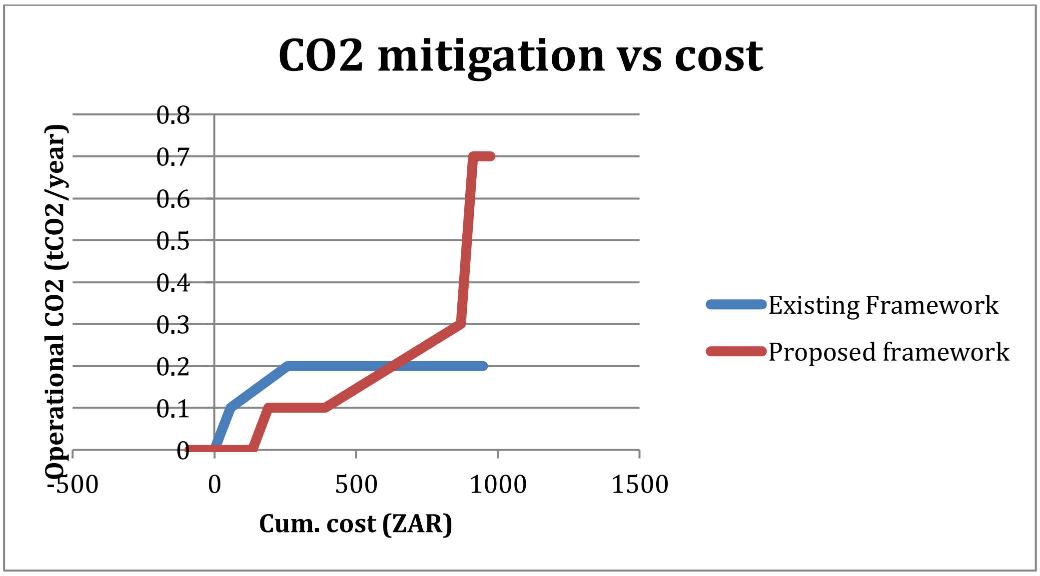

Figure 5.6: CO_2 Mitigation vs. Cost

5.3.2. Water Results

After the technologies were ranked using the effectiveness ratio, the results were cumulated and graphed. The results from the existing and proposed framework are presented graphically to illustrate the need for increased sustainability. Furthermore, it illustrates that a higher sustainability is attainable at a lower cost.

Figure 5.7 represents the relationship between cumulative water savings and cumulative cost. The green line represents the acceptable level of energy savings by the Green Building Council of South Africa (GBCSA), which is 20%. From the figure it is noted that the proposed framework reaches the GBCSA required 20%, around a cumulative cost of R50, whereas the Stellenbosch Municipality (existing) spends nearly R125 and does not reach it.

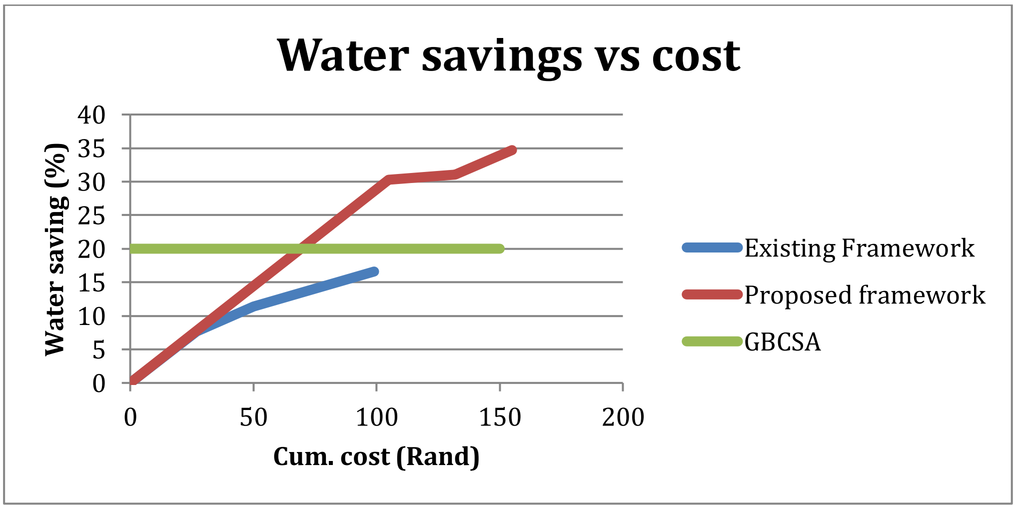

Figure 5.7: Water Savings vs. Cost

Figure 5.8 represents the relationship between cumulative utility reduction and cumulative cost. The figure depicts that with similar cost of technologies, the proposed framework can reduce the monthly utility cost by R70.90 as supposed to R27.10. This will take the strain off the low-income received by the majority of inhabitants in Kayamandi.

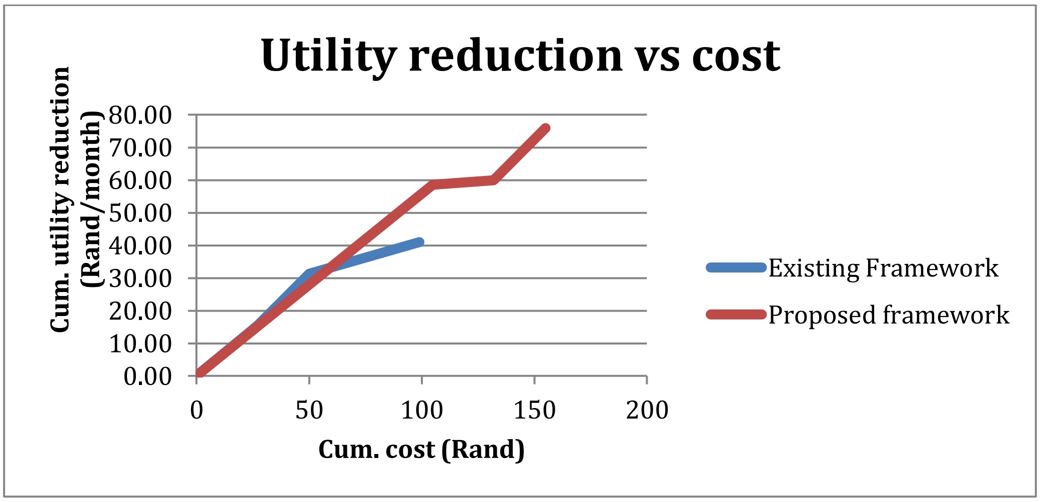

Figure 5.8: Utility Reduction vs. Cost

Figure 5.9 represents the relationship between cumulative years till the technology pays itself back and cumulative cost. The results of the figure represent the total time that it would take the installed technologies to start being beneficial. From the results, it is visible that the proposed technologies pay themselves back sooner than the existing framework.

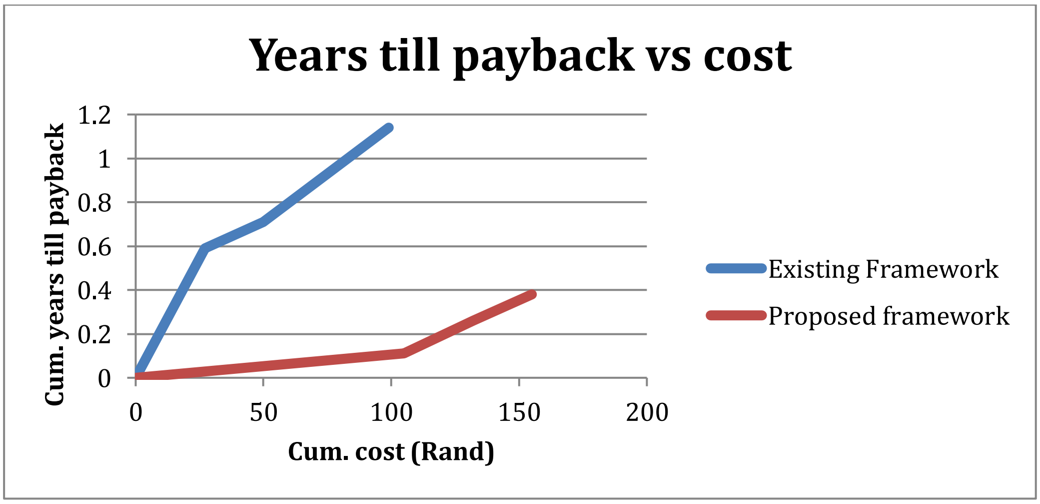

Figure 5.9: Years till Payback vs. Cost

Figure 5.10 represents the relationship between cumulative final monthly water usage and cumulative cost. The figure represents the reduction to the total water consumption per month. The results show a 4kL difference between the two frameworks.

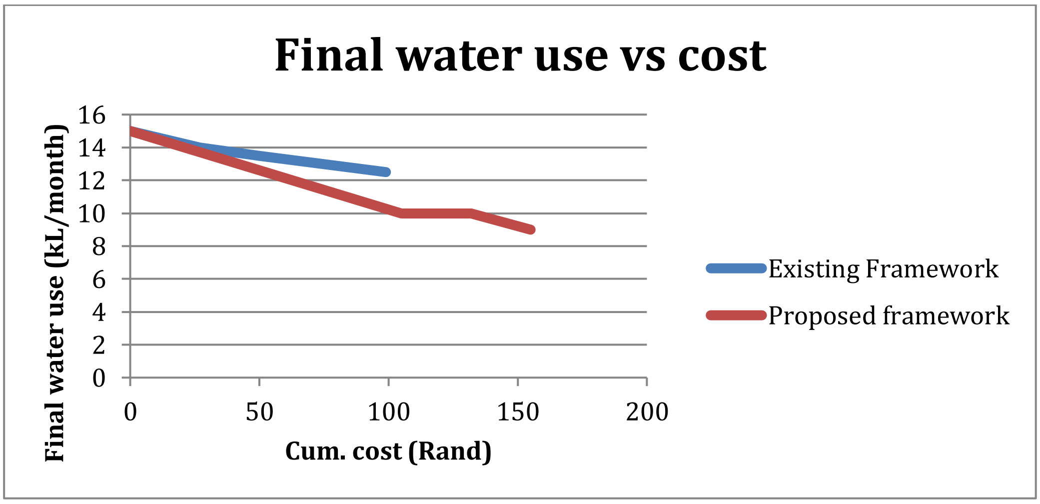

Figure 5.10: Final water use vs. cost

5.3.3. Material Analysis

After the embodied energy of each material was calculated, they were plotted with respect to their effective material savings. The results from the existing and proposed framework are presented graphically to illustrate the need for increased sustainability. Furthermore, it illustrates the amount of energy that could be saved implementing effective technologies.

A linear trend line is fitted to each of the graphs to show the relationship between embodied energy and material (embodied energy) savings. A linear relationship is to be expected because the more sustainably a material is sourced and manufactured, the higher the material savings.

Figure 5.11 represents the relationship between material savings versus each material's embodied energy savings for the construction of floor slabs. From the figure, is noted that the existing framework saves 0 Megajoules (MJ) with 0% material savings, while the proposed framework saves approximately 37550 MJ with 10.3% material savings.

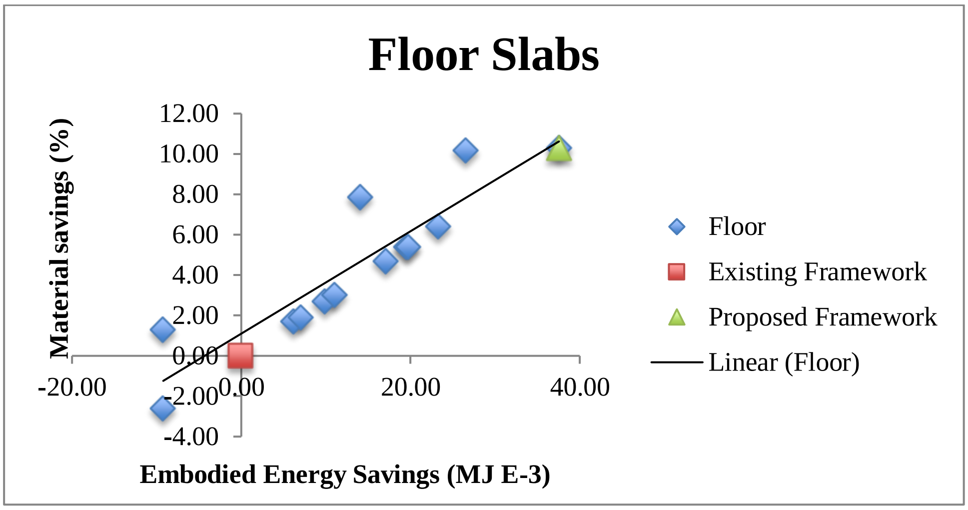

Figure 5.11: Floor Material Savings vs. Embodied Energy Savings

Figure 5.12 represents the relationship between material savings versus each material's embodied energy savings for the construction of roofs. From the figure, is noted that the existing framework saves approximately 2205 MJ with 3.51% material savings, while the proposed framework saves approximately 32740 MJ with 14.96% material savings.

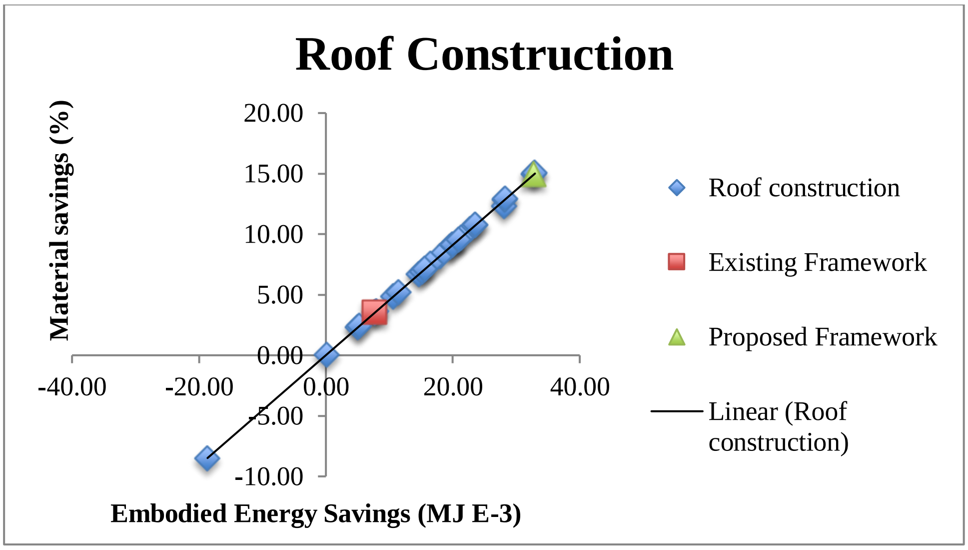

Figure 5.12: Roof Construction Savings vs. Embodied Energy Savings

Figure 5.13 represents the relationship between material savings versus each material's embodied energy savings for the external walls. From the figure, is noted that the existing framework saves 0 MJ with 0% material savings, while the proposed framework saves approximately 69480 MJ with 25.09% material savings.

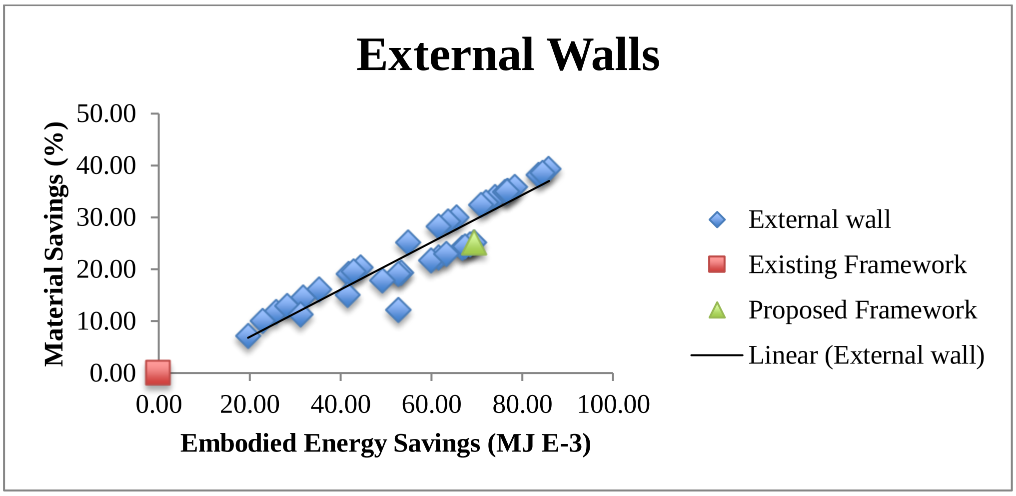

Figure 5.13: External Wall Savings vs. Embodied Energy Savings

Figure 5.14 represents the relationship between material savings versus each material's embodied energy savings for the internal walls. From the figure, is noted that the existing framework saves 0 MJ with 0% material savings, while the proposed framework saves approximately 37025 MJ with 16.92% material savings.

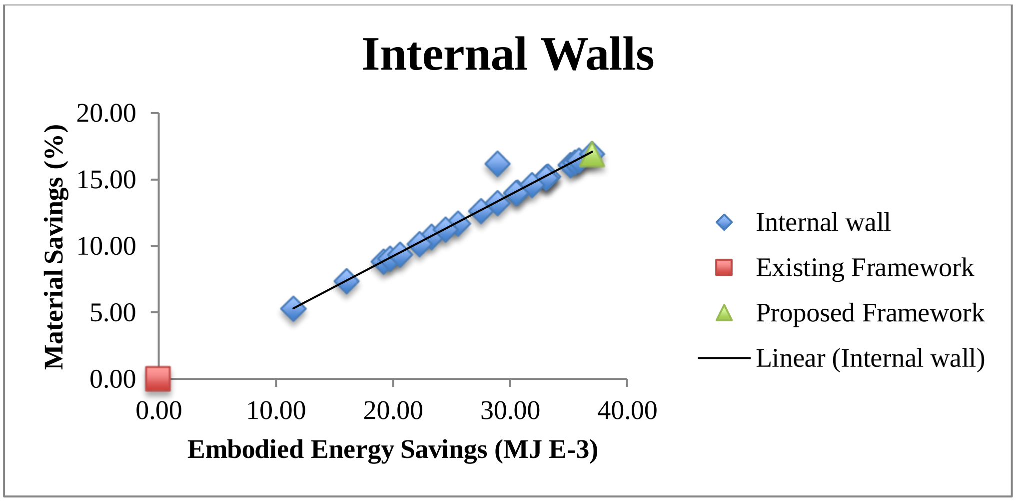

Figure 5.14: Internal Wall Savings vs. Embodied Energy Savings

Figure 5.15 represents the relationship between material savings versus each material's embodied energy savings for the surface beds. From the figure, is noted that the existing and proposed framework save approximately 1815 MJ with 0.83% material savings.

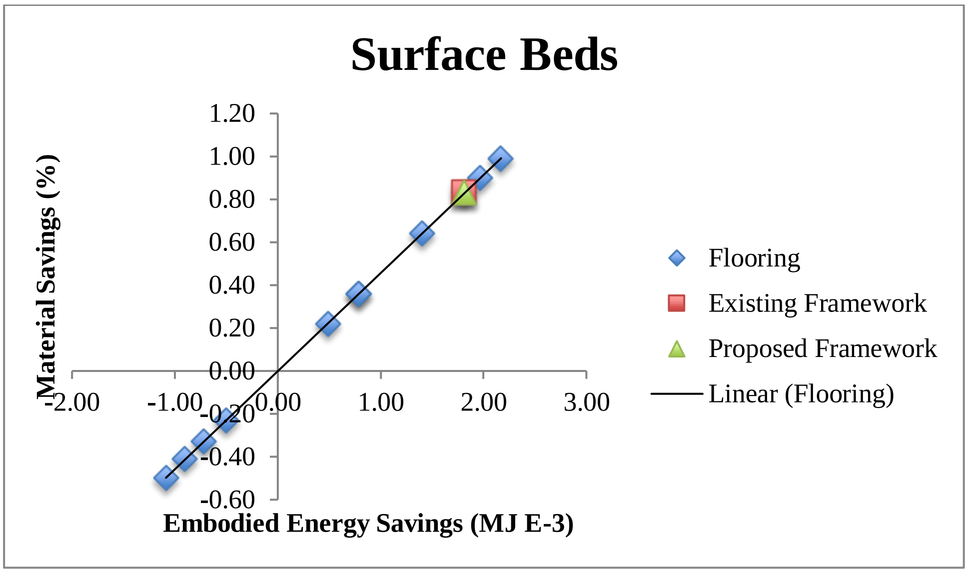

Figure 5.15: Surface Bed Savings vs. Embodied Energy Savings

Figure 5.16 represents the relationship between material savings versus each material's embodied energy savings for the window frames. From the figure, is noted that the existing and proposed framework save approximately 7860 MJ with 3.59% material savings.

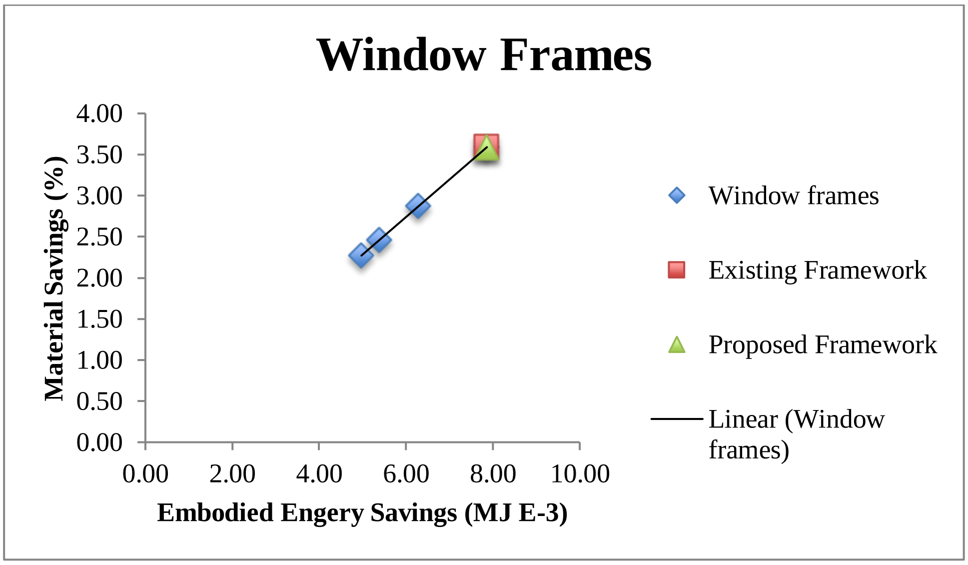

Figure 5.16: Window Frames Savings vs. Embodied Energy Savings

Figure 5.17 represents the relationship between material savings versus each material's embodied energy savings for the roof insulation.

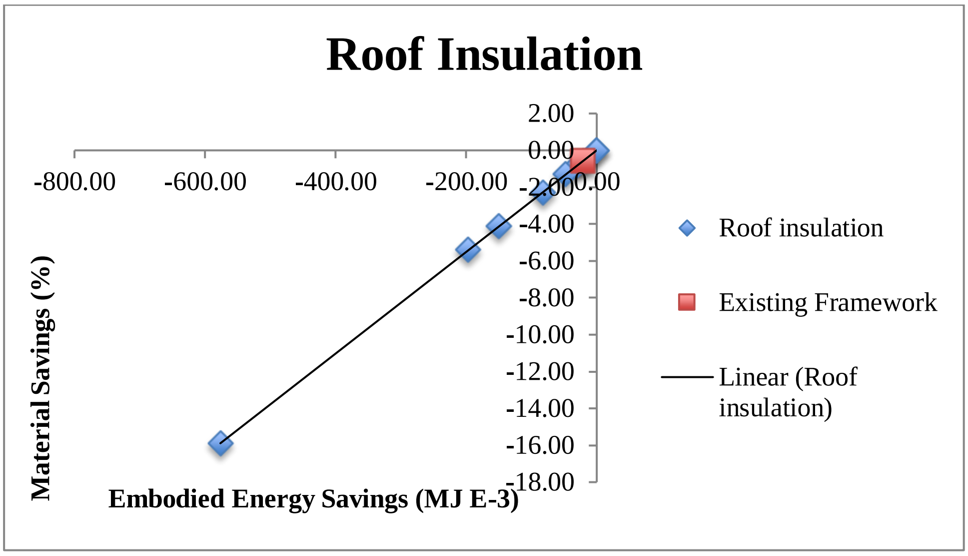

Figure 5.17: Roof Insulation Savings vs. Embodied Energy Savings

Figure 5.18 represents the relationship between material savings versus each material's embodied energy savings for the wall insulation.

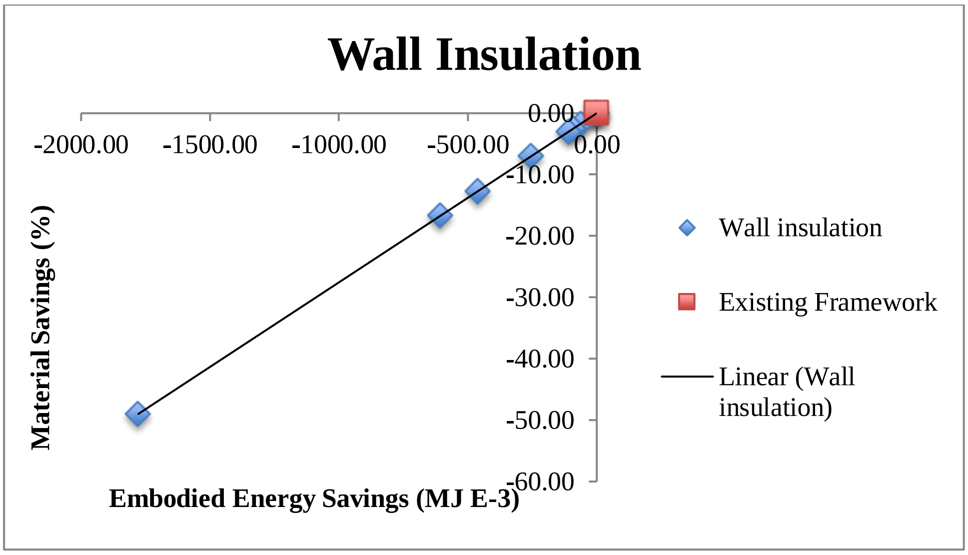

Figure 5.18: Wall Insulation Savings vs. Embodied Energy Savings

In Figure 5.17 and Figure 5.18, the results are presented on two negative axes. This is due to both roof and wall insulation yields a negative material savings and therefore a negative embodied energy savings. This means that installing insulation of any king into a building decreases the materials savings of the building. I.e. more material is used and thus decreases the material savings.

This is to be expected because the base case (previously built dwellings) had air gaps and adding insulation would increase the embodied energy consumption. Figure 5.17 and Figure 5.18 illustrates that in comparison with the rest of the construction material savings, the loss of material savings from adding insulation is miniscule. Additionally, the advantages of insulation exceed the disadvantages significantly.

5.4. Discussion and Conclusion

This Chapter demonstrate the relevance, applicability and level of sustainability of the new frameworks. Moreover, by comparing the results to the Stellenbosch Municipality's framework has made it possible to provide validity of the technologies and strategy proposed by this investigation. It is noted that the materials and water technologies used by the Stellenbosch Municipality perform well, given the strategy confinements.

However, the technologies in the Stellenbosch Municipality's framework performed notably worse than this investigation's proposed framework technologies, which was recommended by My Green Home and GBCSA. This could be a result of the lack of capacity of the Stellenbosch Municipality, the inaccessibility of technologies, the conflicts of terminology in the strategic framework or that certain technologies were simply not considered.

The results of this investigation highlight that the current technological framework, did not meet the sustainability standard recommended by the Green Building Council of South Africa. The framework suggested by this investigation should perform better under the given assumptions. Figure 5.2 and 5.7 are key representatives of the overall performance to be expected from the two frameworks. The technologies available for energy and water are vast and with the correct combination installed into a dwelling, it could dramatically increase the level of sustainability.

With the proposed frameworks highlighted in Section 5.2.1 and Section 5.2.2, a higher level of environmental, economic and social sustainability could be achieved. Furthermore, the results aid in identifying the weaknesses and gaps in current frameworks and highlighted the validity of the proposed framework. These results and graphical representations will allow future frameworks to address sustainability more effectively and therefore enable long-term support to the three pillars of sustainability in settlements.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Overview

This chapter concludes this investigation; the research draws its results and findings from the literature and the case study of Kayamandi. This investigation analyses and responds to all aspects hindering the fulfilment of sustainability within the framework of low-cost housing. Through addressing the economic, social and environmental needs of a settlement, it will increase the standard of living, present numerous economic opportunities and reduce the strain on scarce resources. It should be noted that the alteration of current frameworks and the implementation of the proposed framework is expected to be long processes.

Addressing current frameworks requires economic, social, environmental, institutional, political and societal alignment. Applying the correct pressures on policy makers, public institutions and government is the first step to achieving long-term sustainability. Additionally, these pressures are necessary to meet the constitutional rights of the people of South Africa, as they are being compromised through mismanagement, lack of enforcement and strategy.

This chapter describes how the investigation achieves the research objectives within the provided constraints and limitations. Additionally, it highlights the importance of the research and provides recommendations for future researchers, policy makers and decision makers.

6.2. Conclusions

This investigation aims to provide a benchmark framework from which improvements could be made and to enable South Africa to achieve a sustainable future. The results and findings of this investigation as well as key challenges have been identified and addressed. It is noted that the responsibility to facilitate change falls upon a large integrated community, including the private establishments, government and institutions.

Following is a summary of the findings of this investigation:

Sustainability Within the Construction Sector

Sustainable construction can be defined as *'creating a healthy built environment using resource-efficient, ecologically-based principles'* Kibert (1994b). These principles aim to use resources effectively without harming the surrounding environment. From the literature, it was concluded that the buildings contribute significantly to the environmental degradation of the Earth (Bakhtiar, Li & Misnan, 2008:55). Furthermore, the buildings are responsible for more than 40 percent of energy use and one-third of green house gasses emissions globally (UNEP, 2009).

As a result, concepts such as ‘green buildings’ and ‘sustainable construction’ emerged to address the above-mentioned negative effects. Green buildings initially aimed at reducing the use of non-renewable resources by implementing renewable technologies. Since inception it has evolved past technological innovations and frameworks, to include the economic and social impact they may have. Thus, addressing the three pillars of sustainability.

Sustainability in the global construction sector has therefore evolved dramatically since inception and slowly becoming a prerequisite for any structure. In South Africa, the construction sector has adopted many of the philosophies and principles of sustainability. However, when considering low-cost housing, there is an abundant need for effective technology diffusion and clarity on the principles of sustainability and their implementation.

Effective Methods to Quantify Sustainability

Globally there are numerous methods, systems and benchmarks to measure sustainability in a building. This investigation highlighted the importance of a Life Cycle Assessment when constructing a building, as it assesses the overall environmental impact of a building. From the literature, it was concluded that operating energy accounted for approximately 90% of the energy consumed by a dwelling during its life cycle (Ramesh, et al., 2010, Hernandez, et al., 2010, Ortiz, et al., 2009). It was concluded that reducing operational energies could significantly reduce a dwelling’s lifetime energy expenditure.

To help measure sustainability and quantify the effects technologies had on operating energies (in low-cost housing), this investigation used the online building-rating system called EDGE (Excellence in Design for Greater Efficiencies). This tool was recommended by the Green Building Council of South Africa to achieve a higher level of sustainability in buildings, new and existing. After using EDGE it was noted that available technologies could reduce the energy, water and material consumption in low-cost housing by 30-50 percent. Furthermore, this was achievable without affecting the cost of construction significantly.

Thus, it was concluded that there are tremendously effective methods to quantify the sustainability of a dwelling. Moreover, with the correct systems and building-rating tools introduced into to low-cost housing, it is possible to enable long-term sustainability and reduce energy consumption throughout the country.

Poor Living Conditions in South Africa

It is noted that the living conditions within settlements across South Africa are poor. These conditions are not suitable for the physical and social wellbeing of the inhabitants. Additionally, this expands the number of marginalised groups. While it could be argued that the service delivery is adequate, residents of Kayamandi are noticeably living in poor conditions with no resources to alter their situation and environment. While service delivery in Kayamandi is good (in comparison with the rest of SA), it could still use improvement. It is necessary to meet the needs of inhabitants in these settlements, as it infringes their Constitutional rights (Michelman, 2003).

Existing Frameworks and Policies Shortcomings

The proposed national and provincial frameworks, policies and regulation have a high standard. Although there are concerns with conflict of interests, the general objectives present enough of a platform from which South Africa can develop its settlements and economy. The local strategies within Stellenbosch Municipality are well founded and perform relatively well with respect to other municipalities.

However, the main theme within national and provincial strategies is to develop poor settlements with a focus on economic benefit. Many frameworks ignore the connection between the economy, environment and social welfare of the inhabitants. Thus, adding to the inequality, marginalisation and poverty within the settlements.

This investigation argues there are numerous platforms to achieve sustainable development within all types of settlements, yet local authority does not enable this effectively. Many frameworks include sustainable principles but are not correctly applied or implemented by authoritative bodies. Additionally, sustainable practices are not implemented resulting in housing backlogs, which generally stems from poor resource and capacity mismanagement. The case study of Kayamandi highlights that Section 26 of the Constitution ("Everyone has the right to have access to adequate housing") is not implemented to its full potential and is affect the quality of life of the inhabitants.

Importance of Government and Private Partnerships

Despite the numerous policies and frameworks, the living conditions of the people in South Africa are generally poor. This is directly related to the government's responsibility and performance. It is noted that the government lacks capacity to perform all the required duties and therefore should create more partnerships with the private sector. This will enable a collective effort to establish sustainability in settlements and low-cost housing. The partnerships will increase the amount of community involvement, investment, innovation integration, foreign investment, leadership, capacity and strategic support structures.

Shortcomings of Existing Technological Framework

The results obtained in Chapter 5 indicate that the sustainable frameworks currently proposed by the Stellenbosch municipality require alternative technological innovations. The performance of the buildings directly correlates the level of sustainability within a settlement. From the case study it was concluded that the existing technological framework is not operating efficiently and will not support a sustainable future.

This investigation highlighted that the energy, water and material savings of the existing technological framework did not meet the standards of the Green Building Council of South Africa. Furthermore, a much higher level of sustainability is achievable with a similar cost using more effective technologies.

The current technological framework in Kayamandi and South Africa is valuable in that it makes provision for sustainable systems to be implemented in buildings. The framework is necessary in providing dwellings for the people on subsidy waiting lists. Yet, in terms of sustainability, there is opportunity for enhancement. The technologies available have the capability to decrease the strain on resources, reduce CO_2 emissions and reduce the embodied energies. Thus it would increase the overall sustainability and performance of dwellings.

Shortcomings of Existing Strategic Framework

The case study highlighted the issues with the strategic framework to achieve sustainable development. With Stellenbosch Municipality being among the best municipalities in South Africa, and shortcomings of its strategic framework create concern regarding strategic frameworks employed by other national municipalities. Perceivable concerns indicate that the strategy lacks a general understanding of sustainability in buildings. Additionally, there is an absence of synergy between government, stakeholders and practical mechanisms to achieve sustainable objectives.

It was concluded that government and local municipality lacks capacity to implement the principles of sustainability. Moreover, there is a need for measures and mechanisms to enable sustainable development. Thus, the existing strategic framework needs improving to facilitate sustainable low-cost housing.

Proposed Framework

In Chapter 5, the proposed strategic and technological frameworks demonstrate relevance, applicability and an increased level of sustainability (by GBCSA standards). The proposed strategic framework includes all levels of sustainability and involves adequate interactions with stakeholders, the public sector and the private sector. Furthermore, it is able to achieve a higher level of environmental, economic and social sustainability. Thus, employing the strategy would be beneficial to the general sustainability in low-cost housing.

The results obtained in Chapter 5 emphasises the sustainable performance of the proposed technological framework. It represents this by graphically comparing the results (obtained from the EDGE building-rating tool) of the existing and proposed technological framework. Compared to the case study, it is more energy, water and material efficient. Furthermore, the results illustrate that it possible to increase the sustainability in low-cost housing by 30 to 50 percent by GBCSA standards.

The results provide validity to the proposed framework and aid in identifying the weaknesses and gaps in current frameworks. Furthermore, the graphical representations will allow future frameworks to address sustainability more effectively and therefore enable long-term sustainability for constructing low-cost housing. South Africa is in need of millions of subsidized homes and the Government can incorporate the proposed framework to achieve a sustainable future.

6.3. Recommendations

It is recommended that the proposed framework be continually incremented upon to achieve a higher level of sustainability in the future. Furthermore, construction developers should explore national and international technologies to incorporate into future frameworks. Sustainability is a continual process.

Policy makers and stakeholders can apply this investigation to current policy and strategic frameworks. This investigation recommends that policy should be more stringent on the design of low-cost housing (RDP) and the execution of sustainable principles. Additionally, policy and strategy should be continually reviewed for low-cost housing implementation, as they are easily out-dated.

Decision makers can use this investigation to invest in the Research and Development of technologies to be implemented into future frameworks. Additionally, to use this investigation to improve on current low-cost housing frameworks to make government tenders more favourable. It is also recommended that they invest in sustainable technologies, as the informal sector is an untapped market and could be economically beneficial.

It is recommended that future investigations use alternative rating tools to compare results, to fully quantify the sustainability of future frameworks. It would also be beneficial if the future strategic proposals were accompanied with additional practical mechanisms. Finally, multiple technological and strategic frameworks should be analysed to cultivate a deeper understanding of the various sustainable shortcomings and solutions

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APPENDIX A: POLICY AND STRATEGY REVIEW

A.1. Introduction

This Appendix discusses the policies, strategies and governmental regulations that are responsible for the conceptualization, financing and formation of sustainable housing. Furthermore, the assessment identifies potential gaps in policy that could be amended, to facilitate in the creation of more sustainable settlements. Additionally, the level of community participation that needs to be clearly outlined within each policy created regarding settlement development. This chapter highlights the current policy pressures that fall upon the development of settlements and low-cost housing and the effect that new pressures would have on the biophysical environment.

Since the rule of the African National Congress (ANC) in 1994, many acts and legislations were approved in an attempt to facilitate the creation and administration of localities. There are similarly large amounts of policies and programmes implemented that support the legislation. This chapter is unable to review all policies and programmes that support the creation of sustainable housing. Therefore, only relevant policies, which fall within the scope of informal housing, are assessed with the aim of ascertaining critical weaknesses, pressures and gaps.

A.2. Governmental Policy

The Constitution of the Republic of South Africa

In SA, citizens have the right to housing; which is the responsibility of the state to fulfil this basic human need (Michelman, 2003). Furthermore, the Constitution protects citizens from unlawful expulsions from their dwellings. Section 26 of the Constitution (Michelman, 2003) represents these basic rights and states that:

"Everyone has the right to have access to adequate housing; The State must take reasonable legislative and other measures, within its available resources, to achieve the progressive realization of this right; and no one may be evicted from their home, or have their home demolished, without an order of court made after considering all of the relevant circumstances. No legislation may permit arbitrary evictions."

The concept of sustainable development is likewise included into the Constitution and outlines a similar definition of that prescribed in the Brandtland Report. Having this concept in the Constitution is pertinent to relevant sustainability pursuers and actors in SA, as it allows environmental challenges to be conducted in court (Heyns, et al., 1998):

"Everyone has a right to an environment that is not harmful to their health or well-being; and to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation; and secure ecologically-sustainable development and use of natural resources while promoting justifiable economic and social development."

Reconstruction and Development Programme (RDP)

RDP was first implemented in 1994 to provide a policy that would aid in the development of the new South Africa. The initiative is primarily aimed at meeting the basic needs of the lower economic people of the country, by providing them with housing and necessary services. The RDP (Darkwa, 2006) has six fundamental principles that it hopes to achieve, as listed below:

- The integration of all genders and races by developing the informal sector in a sustainable manner.
- Processes are focused on satisfying the needs of the people.
- Providing a community that is safe and peaceful for all those that dwell in it.
- The broad objective of uniting the country on an economic and social level.

The RDP recognises that sustainable development is one of its fundamental functions, to construct homesteads in a sustainable manner. Thus, it became the stepping-stone for other government policies to build on, to further increase the sustainability in the construction sector (Michelman, 2003). The RDP's 'people-driven' approach creates a platform where there is equal prospect for people to achieve and secure a long-term sustainable future for themselves and their localities.

The South African Housing Act

The SA Housing Act was introduced in 1997, encapsulating the government's solution to every South African's constitutional right to adequate housing. Additionally, it highlights general principles that apply to the construction of dwellings and presents strategies to proceed with developments in a sustainable manner. The Act describes the role of government from a national to local level with respect to settlement development (Michelman, 2003). Furthermore, it oversees the management of the South African Housing Board, provincial boards and the resources coupled to the development of the houses.

The Act encourages all authoritative figures to consult with inhabitants in the community to understand the spectrum of housing needs within the settlements (Michelman, 2003). According to the Act, the settlements developed are required to be financially viable, ecologically and biophysically friendly and socially and culturally acceptable. Thus, meeting sustainability on all levels. The housing is required to be distributed equally and equitably, with the correct administration and ideologies of good governance.

However, the expectations and delivery of adequate housing are not met on frequent occasions. It could be argued that the supposed ‘needs’ articulated by the consulted inhabitants, often constrain the solutions to the SA housing dilemma. Either the ‘needs’ are unrealistic, or they do not promote a strong long-term sustainable settlement. The housing policy also requires flexibility as the ‘needs’ of the inhabitants vary between localities. Furthermore, the recipients of housing are unable to obtain separate subsidies to develop their own dwelling, as they are predominantly available when an entire settlement is being developed. Therefore, the Housing Act is relevant in promoting sustainability, yet lacks the necessary mechanisms to effectively achieve it with the given resources.

Growth, Employment and Redistribution Strategy (GEAR)

GEAR was introduced to SA after the implementation of RDP in 1994. It serves as an economic strategy to facilitate and strengthen the growth of all economies in SA. The strategy takes a macroeconomic approach to provide more employment and provide it primarily among the poor people of SA. The primary focus of GEAR is to strengthen SA’s economy for it to become more competitive in global markets and more attractive to foreign investors (Nguyen, et al., 2011). The manner, in which GEAR hopes to achieve this, is by creating intense competition between the respective provinces and cities. However, this method does not necessarily ensure that there will be an equal distribution of employment opportunities.

It is also noted by Nguyen, et al., (2011) that there are some inconsistencies concerning the achievement of economic development versus the delivery of human rights and services between RDP and GEAR. Nevertheless, RDP and GEAR, to a certain degree; affect the policies and the way they are thought out and implemented. This does not necessarily bode well for environmental sustainability because it could be argued that GEAR does not have a secure long-term strategy to ensure sustainable development in settlements. Understandably it is imperative for SA to engage in strong economic development to achieve a sustainable nation but is not a feasible solution when it comes at the expense of the biophysical and social environment. It is in this light that GEAR is proven to be inadequate. (Nguyen, et al., 2011).

A.3. Policy Pressures

Following is a summary of emerging trends that have occurred in policy implementation.

Basic rights and services

According to the South African Constitution (Michelman, 2003), one of the primary roles the government must fill is to satisfy the basic needs of the people of SA, including basic services and housing. Fulfilling these basic needs is to be conducted in an affordable manner to benefit the people as well as the state. Currently, there are enormous backlogs in providing quality housing and basic services (Tushnet, 2003).

With a combination of insufficient planning and funds, the government is forcing municipalities to reach their housing targets with poorly constructed dwellings, which are below normal quality standards. This has resulted in numerous settlements with poor infrastructure that lacks social and economic security. The living standards of these settlements are not acceptable on all levels of sustainability and subsequently do not promote a positive change in SA (Tushnet, 2003).

Pressure from stakeholders and the public is to improve the quality of the housing and services, in addition to meeting the targets set out by the government. The focus has thus far been primarily on capital cost and affordability of the housing, which is slowly shifting to ensuring that the provision of basic needs and services are met affordably. Additionally, the basic services need to be affordable for recipients by ensuring that the operational costs do not exceed the inhabitant's income (Tushnet, 2003).

Economic policy

According to Pycroft (2000), GEAR outlines that the SA economic policy is a response to the inevitability of globalisation, by attempting to obtain a foothold in the global economy, attracting foreign investment, increasing the influence of the private sector and reducing the responsibility of the central state. It could be argued that the economic policy was implemented as a result of a lack of skills and finances in the public sector, which limited the provision of basic services (Du Plessis & Landman, 2002) .

To resolve this situation, the government has made partnerships between the private and public sector to provide financial support for the development of infrastructure and basic services. The economic policy has caused the emergence of three major pressures, as highlighted by Du Plessis & Landman (2002):

(1) Privatisation of service delivery

There are numerous cases where the local authorities are outsourcing their services to private companies, which are profit orientated. While this does provide great opportunity and growth in the private sector, it could be argued that it would be an infeasible option for many inhabitants in informal settlements; as the services may cost more than their income can afford (Pycroft, 2000). Nevertheless, privatising service delivery would ensure that effective and efficient services are rendered and integrating sustainability into policy would be easier.

(2) Privatisation of formal space

When developing a human settlement, it requires financial risk from developers and investors. Privatising formal spaces would enable inhabitants and investors to protect their commodities and increase the level of security against outcomes that could oppose their investments. An example of this emerging trend is inhabitants enclosing their neighbourhoods with fences or the blocking of unauthorised street access. Numerous local authorities permit these enclosures where the entire neighbourhood is privatised apart from the road still belonging to the municipality. There numerous forms of private local governments where businesses or residents oversee the services within the area. It is noted that this falls closely in line with privatising service delivery, and therefore has similar advantages and disadvantages (Michelman, 2003).

(3) National distribution of finances and investment

This pressure aims at discovering and exploiting areas that have potential for sustainable economic growth with the help of resources provided by the public sector. The Spatial Development Initiative (SDI) encapsulates this pressure (Tushnet, 2003). The SDI focuses on increasing the profile and attractiveness for investment of a specific region. According to (Jourdan, 1998:717) , the SDI aims to:

- Facilitate and promote export orientation between different businesses in SA.
- Increase the amount of foreign exchange acquired by SA.
- Ensure the effective use of available resources and infrastructure.
- Facilitate and ensure the creation of sustainable employment.
- Extend the tenure base of the economy.

Although the SDI has suitable objectives to attain a sustainable economy, the effectiveness of the initiative could be questioned. According to (Du Plessis & Landman, 2002) , the SDI has not attracted as many investors as anticipated, yet it has made a considerable impact to a few severely poor regions. The disadvantage of focusing resources in a region is that the existing industrial areas are susceptible to losing employees to the SDI, which will subsequently forfeit large investments made by the private sector (Tushnet, 2003).

Adjusting the structure of local government

To address the issues created by the Apartheid government, a major restructuring in authority and government on a national, provincial and local level was conducted since 1994. The process as a whole affected most sectors in SA, if not all, and became a major engine of change. It has correspondingly placed pressure on three major aspects on human settlements and are listed following (Michelman, 2003).

(1) Municipal transformation

Municipalities have combined resources across areas that receive high and low service quality, which has resulted in lowering expenditures and leaner establishments (Jourdan, 1998:717). It could be argued that this action was at the cost of efficiency and effectiveness, resulting from added pressures on the need of skilful labour. However, like any restructuring, time will be needed to adjust to the new system.

(2) Legal obligation of local authorities to plan developments

Local authorities have a legal obligation to plan development, which will increase the level of sustainability within the human settlements. Yet, the processes that are being pushed require a higher level of planning and skilled labour, which could subsequently result in the local authorities being unable to meet their housing targets (Du Plessis & Landman, 2002) Additionally, adding to problem of housing backlogs and poor service delivery.

(3) Local government responsible for development

The new policies and regulation (e.g. GEAR) have placed a large responsibility on local governments to develop human settlements without any aid. Additionally, the local government is provided with a fixed rate and is meant to achieve all their goals within the confines of the budget. For many areas, this has not been possible and results in poorly constructed settlements at the cost of sustainability on all levels (Tushnet, 2003).

Although the intentions and pressures received by the local government are in the best interest of the people, the resources and skills needed, in several cases, do not match those that they are provided with.

A.4. Policy Gaps and Tensions

The pressures that have emerged since 1994 because of policy, have achieved an evident awareness of sustainability, which is noticeable in human settlements. While positive change is currently proceeding within local government and municipalities, there are noticeable gaps and tensions within the policies and are discussed following.

Local government responsibility

Policy defines the scope of responsibility that the local government and municipality have within developing and developed settlements. It needs to outline the role that the officials have in the delivery of quality services, adequate sustainable housing and resource management. It would be further beneficial if the policies included practical mechanisms that aided the authorities to apply and enforce the principles and requirements within the documents.

Terminology

It is imperative that terminology be introduced and used in policy in the correct manner, as it affects the implementation and understanding of the requirements of the policy. Policies also need to convey how sustainable principles and fundamentals are implemented in human settlements, otherwise the ideals of sustainability would be lost and incorrectly applied. Furthermore, it would be beneficial if sustainable principles and applications were explained thoroughly to make them adaptable to any locality or region.

National policy implementation standards

The policies in SA have a high standard and are parallel with the best around the globe (Du Plessis & Landman, 2002) . Like local government responsibility, the policies are not accompanied with practical mechanisms that enable them to be properly implemented. Thus, it is apparent that the standards of implementation do not mirror the quality of the policies themselves (Michelman, 2003). There is a need to include achievable objectives within the policies that are within the scope of SA's financial resources and available skills. However, is unlikely that SA would be able to accomplish the goals set out by policies that are paralleled with developed countries.

State and government involvement

Numerous policies commonly place most of the responsibilities on communities, NGO and private entities to deliver quality housing and services. Removing the state or from the enabling roles increases the pressures felt by these organisations to deliver and diminishes the authoritative influence of the government (Tshikotshi, 2010). Furthermore, this could potentially add to the misuse of crucial resources provided by the state, as there is no authority appropriately monitoring progress. Leaving the responsibility on private entities could result in a decrease in sustainability in human settlements, as the organisations will undoubtedly be more profit orientated or focused on cost recovery than government (Tshikotshi, 2010).

Community involvement

Unlike the RDP, recent policies do not place emphasis on the importance of community involvement and interaction (Jourdan, 1998:717). Not involving the community could negatively affect (1) the innovations that are created from bottom-up invention, (2) the support to enable effective change and (3) the sustainability within the settlements.

Additionally, omitting community involvement from policy creates a barrier of communication between government and inhabitants. This further disables the community to solve issues within their settlements and subsequently decreases the living standards (Jourdan, 1998:717). While numerous policies do include the involvement of the communities, they disregard the functions and participation of community-inspired organisations (Du Plessis & Landman, 2002) .

In contrast to this, having community participation could potentially negatively impact the housing and service delivery in a settlement. While many of the community participants may have the best interest of the community in mind, they could unintentionally end up wasting valuable resources and causing further backlogs.

Sustainability Tensions: Economic vs Environmental

There are numerous policies that focus on the preservation of the biospherical environment in SA. They are focused on the preservation and conservation of the land, resources and ecological life. While these policies are necessary and attempt to create awareness on environmental sustainability, in several cases they ignore the concerns surrounding the economic pillar of sustainability (Tshikotshi, 2010)The policies appear to be satisfying long-term environmental achievements without considering the long-term economic welfare of SA. This illuminates that policies often contradict each other and do not appear to have similar objectives.

Formal and Informal Tensions

According to (Tshikotshi, 2010) , there is a lack of coherence in policies when considering the methods prescribed to deal with the concerns of development in formal and informal

settlements. The policies created should interconnect informal and formal settlements in a strategic manner. However, creating and applying the same policies to both types of settlements will result in a struggle to implement them and reduce their effectiveness.
Recent policies tend to combine informal and formal settlements in many aspects. This consequently increases the amount of pressure on local government and municipalities to adapt the policies to suit their dominion's issues. As previously noted, creating policies that do not provide practical mechanisms to achieve sustainable development, result in poor service and housing delivery.

Although, with the close integration of formal and informal settlements in policies, it is even more likely that local government and municipalities are unable deliver sufficiently. Therefore, policies should include strategy and practical mechanisms that enable local authorities to distinguish between informal and formal settlements and what would be applicable to them individually.

A.5. Conclusion

From the policy review, it is possible to note that there are several gaps within the policies of SA that need adequate redressing, to effectively solve the sustainability issues within informal settlements. In South Africa there is room for improvement in increasing the level of sustainable development.

The issues arise when new national policies are created, as their mechanisms of translation and implementation do not translate well to a local level. This can be accounted to numerous institutional barriers, with the most consequential including (Michelman, 2003):

- Insufficient financial support and strategic planning for developing new and existing settlements.
- Inadequate practical mechanisms in policies to aid local government with sustainable settlement development.
- Insufficient resources allocated to local government, including necessary skills, finances and applicable strategic management.
- Lack of remuneration for community involvement to mitigate the negative effects on the environment.
- Long-term and committed involvement from the government on a local and national level.
- The lack of responsibility assignment within the processes to achieve a sustainable settlement.

Policies use a vast selection of terminology that is often misinterpreted. As a result, it hinders the ability of the policy to reach its objectives, as they are often not properly understood. This gap would imply that the people creating and overseeing the policies do not fully understand how interconnected sustainable development is with the economy, biophysical and social environment. This would consequently result in the proposal of inadequate mechanisms to accomplish sustainable development in informal settlements, even if the policy presents itself with a strong sense of sustainability.

The most noticeable and arguably the biggest gap in policies, is the fact that they are not correctly implemented or enforced. While it is appropriate to have adequate policies that would create a long-term sustainable country, it is a completely different matter to what is applied in practice on the ground level. There is a significant amount of evidence that suggests the ideologies of the policies are insufficiently transferred to producing sustainable development.

Therefore, it would be in the best interest of informal settlements in SA, if the existing policies: (1) contain easily understood material, (2) include definitions of terminology and their implications, (3) be merged into coherent frameworks that clearly outline similar objectives, (4) were accompanied with practical mechanisms to achieve sustainability, (5) outlined the roles and responsibilities of local municipalities and government, and (6) created a channel for authorities to obtain necessary funding and resources

APPENDIX B: KAYAMANDI CONTINUED

B.1. Introduction

This section is a continuation of the living standards and services in Kayamandi. It was included in the Appendices to provide further background on the quality of life experienced by the people.

B.2. Demographic

Of the approximate population of 35 000 inhabitants in Kayamandi, 75% of them are below the age of 34. The difference between genders is minimal, with males occupying a total of 49.9% and females 51.1%. The racial separation of the population is black 94%, coloured 4.7%, white 0.2%, Asian 0.1% and other 0.5%. With regards to education, the inhabitants are particularly underprivileged with only 4.3% of the total population attaining a higher education. Table B.1 summarises the education status of rest of Kayamandi.

Table B.1: Kayamandi Education Status (StatsSA, 2011)

Education	Percentage of population
No schooling	2.2
Some primary schooling	11
Completed primary school	5.3
Some high school	48.7
Matriculation	28.6
Tertiary	4.3

B.3. Household Inhabitants

The 2007 Community Survey stated that 23% of shack inhabitants comprised of a single person, with 50% of them being under 35 years of age. According to the HDA (2013), this anomaly might occur for the following reasons:

- The individual finds it more convenient to live closer to their work.
- It is more economically beneficial.
- Work is too far to commute daily.
- The individual is unmarried or single
- Family members reside in different provinces.

According to the Census in 2001 (Census, 2001), the average number of inhabitants in shacks was 3.2 per shack. This average remained the same six years later in the Community Survey in 2007 (HDA, 2012). Households with four or more inhabitants accounted for 38%, while

22% live in overcrowded conditions (HDA, 2012). According to du Plessis (2007), overcrowding is prevalent for people living in informal dwellings and as a result, the inhabitants have a low standard of living

B.4. Living Conditions and Services Continued

Latrine facilities

The inhabitants of Kayamandi generally have access to good sanitation facilities, the delivery of latrines has increased dramatically since 2007. Furthermore, unlike numerous informal dwellings in SA, majority of Kayamandi's sanitation facilities are connected to an adequate sewerage system. There are minimal households that do not have access to flushable latrines. According to StatsSA (2011), 95.2% of the inhabitants have access to a flushable toilet, with only 0.6% connected to a septic tank. Alternate forms of sanitation include chemical latrines, pits, buckets or none.

Refuse disposal

Household refuse disposal services are conducted, in partnership, by local authorities and private companies (Darkwa, 2006). Refuse disposal services accounted for 84.1% in 2001 (Census, 2001). Subsequently, the removal of waste increased to 88.4% by 2007 and further increased to 90.7% by 2011 (StatsSA, 2011). Alternate methods of refuse disposal, with their percentage of access, is summarised in Table B.2. A key concern is inhabitants that have no access to refuse disposal. Although they comprise a small percentage of the total residents, it could be hazardous to their general health.

Table B.2: Refuse Disposal (StatsSA,2011)

Refuse disposal	Percentage
Removed by local authority/private company at least once a week	90,7%
Removed by local authority/private company less often	0,3%
Communal refuse dump	5,8%
Own refuse dump	1,9%
No rubbish disposal	0,6%
Other	0,7%

APPENDIX C: ANALYSIS OF EXISTING AND PROPOSED TECHNOLOGICAL FRAMEWORK

C.1. Introduction

The following Appendix provides the results of the analysis conducted on the current technological framework implemented in Kayamandi as well as the proposed technological framework by this investigation. The analysis was conducted on water, energy and material specifications of the current technological framework.

Technologies were analysed separately using the EDGE building software and the various factors that have an impact on sustainability were taken into account. Factors include cost, energy savings, CO_2 mitigation, etc. EDGE bases its results on locally adjusted data from utility costs, climate statistics and building regulations (GBCSA, 2012). This helps provide the user with a realistic, concurrent evaluation and performance of a building in South Africa. To further improve the accuracy of the results, EDGE requires the geographical location, the type of unit (e.g. single story) and number of inhabitants. The results were ranked according to rand spent per energy or water savings percentage; this was to gauge which technologies were most economical for the environment.

C.2. Existing Framework

Table C.1: Water Analysis

Technology	Additional cost of technology (Rand/unit)	Utility costs reduction (Rand/month/ unit)	Total utility cost (Rand/month/ unit)	Years till technology pays itself off	Operational CO2 mitigation (tCO2/year)	Electricity use (kW/month/ unit)	Water use (kL/month/ unit)	Water savings (%)	Energy savings (%)	Rand spent per water savings ratio (Rand/%)
Base case/standard	0	0	365	0	0	187.2	15	0	0	0.00
Single Flush for Water Closets - 6 lt./flush	27	15.49	349.51	0.59	0	187.2	14	7.7	0	3.51
Low-Flow Showerheads - 8 lt./min	23	15.8	349.2	0.12	0.1	178	14.5	3.7	3.3	6.22
Low-Flow Faucets for Kitchen Sinks -6 lt./min	49	9.68	355.32	0.43	0	187.2	14	5.2	0	10.21

Table C.2: Water Analysis (cont.)

Technology	Cumulative cost (Rand)	Cum. utility reduction (Rand/month)	Cum. years till technology payback	Cumulative water savings (%)	Water (kL/month)
Base case/standard	0	0.00	0	0	15
Single Flush for Water Closets - 6 lt./flush	27	15.49	0.59	7.7	14
Low-Flow Showerheads - 8 lt./min	50	31.29	0.71	11.4	13.5
Low-Flow Faucets for Kitchen Sinks -6 lt./min	99	40.97	1.14	16.6	12.5

Legend	
(blue)	Cooling energy
(orange)	Hot water
(green)	Appliances
(yellow)	Lighting
(purple)	Appliances/ Hot water/ Lighting

Table C.3: Energy Analysis

Technology	Additional cost of technology (Rand/unit)	Direct utility costs reduction (Rand/ month)	Total utility cost (Rand/ month)	Operational CO2 mitigation (tCO2/year)	Years till tecnology pays itself off	Electricity use (kW/month)	Energy savings (%)	Rand spent per energy savings ratio (Rand/%)
Natural Ventilation	0	0	326	0	0	138.8	3.62	0.00
High Efficiency Boiler for Space Heating - Efficiency of 0.90	57	6.37	319.63	0.1	0.76	130.2	2.3	24.78
Solar Hot Water Collectors - 60% of Hot Water Demand	202	16.76	309.24	0.2	1	120.4	2.4	84.17
Energy-Saving Light Bulbs - Internal Spaces	45	2.34	323.66	0	1.6	136.3	1.1	40.91
Energy-Saving Light Bulbs - Outdoor Areas	60	1.87	324.13	0	2.67	138	1.3	46.15
Reflective paint/tiles for roof - 50% solar reflection	161	0	326	0	1.3	138.8	1.9	84.74
Insulation of Roof - U Value of 0.18	423	0	326	0	3.53	138.8	3.5	120.86

Legend	
(blue)	Cooling energy
(orange)	Hot water
(green)	Appliances
(yellow)	Lighting
(purple)	Appliances/ Hot water/ Lighting

Table C.4: Energy Analysis (cont.)

Technology	Cumulative cost (Rand)	Cum. utility reduction (Rand /month)	Cum. years till technology payback	Cumulative energy savings (%)
Natural Ventilation	0	0	0	3.62
High Efficiency Boiler for Space Heating - Efficiency of 0.90	57	6.37	0.76	5.92
Solar Hot Water Collectors - 60% of Hot Water Demand	259	9.06	1.63	8.32
Energy-Saving Light Bulbs - Internal Spaces	304	11.38	2.09	9.42
Energy-Saving Light Bulbs - Outdoor Areas	364	12.11	2.29	10.72
Reflective paint/tiles for roof - 50% solar reflection	525	12.24	3.2	12.62
Insulation of Roof - U Value of 0.18	948	12.24	3.6	16.12

Legend	
	Floor Slabs
	Window frames
	Surface Beds
	Internal walls
	Roof
	External walls

Table C.5: Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)	Cum. Electricity savings (kWh)	Cumulative EE savings (%)
Base case: In-situ reinforced concrete slab	0.00	0.00	0.00	0	0
Common brick wall with internal and external plaster	0.00	0.00	0.00	0.00	0.00
Common brick wall with plaster both sides	0.00	0.00	0.00	0.00	0.00
Finished floor concrete	1813.25	520.40	0.83	520.40	0.83
Timber	7863.69	2256.88	3.59	2777.28	4.42
Aluminium sheets on timber rafters	7682.99	2205.02	3.51	4982.30	7.93

C.3. Proposed Framework

Table C.6: Water Analysis

Technology	Additional cost of technology (Rand/unit)	Utility costs reduction (Rand/month/ unit)	Total utility cost (Rand/month/ unit)	Years till technology pays itself off	Operational CO2 mitigation (tCO2/year)	Electricity use (kW/month/ unit)	Water use (L/month /unit)	Water savings (%)	Energy savings (%)	Rand spent per water savings ratio (Rand/%)
Base case/standard	0	0	326	0	0	138.8	15	0	0	0.00
Recycled Grey Water for Flushing	105	58.6	267.4	0.11	0	141	10	30.3	0.8	3.5
Single Flush for Water Closets - 6 lt./flush	27	15.49	310.51	0.59	0	138.8	14	7.7	0	3.51
Low-Flow Showerheads - 8 lt./min	23	15.8	310.2	0.12	0.1	129.6	14.5	3.7	3.3	6.22

Table C.7: Water Analysis (cont.)

Technology	Cumulative additional cost (Rand)	Cum. utility reduction (Rand/month)	Cum. years till technology payback	Cumulative water savings (%)	Water (kL/month)
Base case/standard	0	0.00	0	0	15
Recycled Grey Water for Flushing	105	58.60	0.11	30.3	10
Single Flush for Water Closets - 6 lt./flush	132	59.89	0.26	31	10
Low-Flow Showerheads - 8 lt./min	155	75.90	0.38	34.7	9

Legend	
(blue)	Cooling energy
(orange)	Hot water
(green)	Appliances
(yellow)	Lighting
(purple)	Appliances/ Hot water/ Lighting

Table C.8: Energy Analysis

Technology	Additional cost of technology (Rand/unit)	Utility costs reduction (Rand/month/ unit)	Total utility cost (Rand/month/ unit)	Operational CO2 mitigation (tCO2/year)	Years till technology pays itself off	Electricity use (kW/month/ unit)	Energy savings (%)	Rand spent per energy savings ratio (Rand/%)
Reduced window to wall ratio - 9%	-88	0	326	0	0	138.8	2.5	-35.20
Natural Ventilation	0	0	326	0	0	138.8	3.62	0.00
Low-E Coated Glass - U Value of 3 W/m² K and SHGC of 0.45	221	0	326	0	1.1	138.8	11.5	19.22
High Efficiency Boiler for Space Heating - Efficiency of 0.90	57	6.37	319.63	0.1	0.76	130.2	2.3	24.78
Solar Hot Water Collectors - 70% of Hot Water Demand	202	16.76	309.24	0.2	1	120.4	6.6	30.61
Solar Photovoltaics - 25% of Total Energy Demand	477	37.9	288.1	0.4	1.05	97.2	14.7	32.45
Energy-Saving Light Bulbs - Internal Spaces	45	2.34	323.66	0	1.6	136.3	1.1	40.91
Energy-Saving Light Bulbs - Outdoor Areas	60	1.87	324.13	0	2.67	138	1.3	46.15

Legend	
	Cooling energy
	Hot water
	Appliances
	Lighting
	Appliances/ Hot water/ Lighting

Table C.9: Energy Analysis (cont.)

Technology	Cumulative cost (Rand)	Cum. utility reduction (Rand /month)	Cum. years till technology payback	Cumulative energy savings (%)
Reduced window to wall ratio - 9%	-88	0	0	2.5
Natural Ventilation	0	0	0	6.12
Low-E Coated Glass - U Value of 3 W/m² K and SHGC of 0.45	133	0	1.1	17.62
High Efficiency Boiler for Space Heating - Efficiency of 0.90	190	6.37	1.5	19.92
Solar Hot Water Collectors - 70% of Hot Water Demand	392	19.13	1.85	26.52
Solar Photovoltaics - 25% of Total Energy Demand	869	49.63	2.25	41.22
Energy-Saving Light Bulbs - Internal Spaces	914	51.27	2.4	42.32
Energy-Saving Light Bulbs - Outdoor Areas	974	51.87	2.6	43.62

Legend	
(yellow)	Surface Bed
(orange)	Window frames
(red)	Floor Slabs
(green)	Internal walls
(purple)	Roof
(blue)	External walls

Table C.10: Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)	Cum. Electricity savings (kWh)	Cumulative material savings (%)
Finished Concrete	1813.25	520.40	0.83	520.40	0.8
Timber	7863.69	2256.88	3.59	2777.28	4.42
Timber floor construction	37550.0	107.77	10.30	2885.05	14.72
Rammed earth blocks/walls	37026.03	10626.47	16.92	13511.52	31.64
Asphalt shingles on timber rafters	32738.64	9395.99	14.96	22907.51	46.6
Rammed earth blocks/walls	69480.50	19940.90	25.09	42848.41	71.69

APPENDIX D: ANALYSIS OF ALL GBCSA TECHNOLOGIES

Table D.1: Water Analysis

Technology	Additional cost of technology (Rand/unit)	Utility costs reduction (Rand/month/unit)	Total utility cost (Rand/month/unit)	Years till technology pays itself off	Operational CO2 mitigation (tCO2/year)	Electricity use (kW/month/unit)	Water use (L/month/unit)	Water savings (%)	Energy savings (%)	Rand spent per water savings ratio (Rand/%)
Base case/standard	0	0	326	0	0	138.8	15	0	0	0.00
Recycled Grey Water for Flushing	75	58.6	267.4	0.11	0	141	10	30.3	-0.8	2.48
Single Flush for Water Closets - 6 lt./flush	27	15.49	310.51	0.59	0	138.8	14	7.7	0	3.51
Low-Flow Showerheads - 8 lt./min	23	15.8	310.2	0.12	0.1	129.6	14.5	3.7	3.3	6.22
Dual Flush for Water Closets - 6 lt./first flush and 3 lt./second flush	109	33.88	292.12	0.82	0	138.8	13	16.9	0	6.45
Low-Flow Faucets for Kitchen Sinks -6 lt./min	49	9.68	316.32	0.43	0	138.8	14	4.8	0	10.21
Low-Flow Faucets for All Bathrooms - 6 lt./min	49	9.68	316.32	0.43	0	138.8	14	4.8	0	10.21
Recycled Black Water for Flushing	496	56.54	269.46	0.73	-0.1	144.7	10	31	-2.1	16.00
Rainwater Harvesting System - 50% of Roof Area Used for Rainwater Collection	936	6.46	319.54	12.08	0	138.8	14.5	3.2	0	292.50

Table D.2: Water Analysis (cont.)

Technology	Cumulative cost (Rand)	Cum. utility reduction (Rand/month)	Cum. years till technology payback	Cumulative water savings (%)	Water (kL/month)
Base case/standard	0	0.00	0	0	15
Recycled Grey Water for Flushing	75	58.60	0.11	30.3	10
Single Flush for Water Closets - 6 lt./flush	102	59.89	0.26	31	10
Low-Flow Showerheads - 8 lt./min	125	75.90	0.38	34.7	9
Dual Flush for Water Closets - 6 lt./first flush and 3 lt./second flush					
Low-Flow Faucets for Kitchen Sinks -6 lt./min	174	85.57	0.81	39.5	8
Low-Flow Faucets for All Bathrooms - 6 lt./min	223	95.52	1.24	44.4	8
Recycled Black Water for Flushing					
Rainwater Harvesting System - 50% of Roof Area Used for Rainwater Collection	1159	101.97	13.32	47.6	8

Legend	
	Cooling energy
	Hot water
	Appliances
	Lighting
	Appliances/ Hot water/ Lighting

Table D.3: Energy Analysis

Technology	Additional cost of technology (ZAR/unit)	Direct utility costs reduction (ZAR/ month)	Total utility cost (ZAR/ month)	Operational CO2 mitigation (tCO2/year)	Years till technology pays itself off	Electricity use (kWh/month)	Energy savings (%)	Rand spent per energy savings ratio (ZAR/%)
Base case/standard	0	0	326	0	0	138.8	0	0.00
Reduced window to wall ratio - 9%	-88	0	326	0	0	138.8	2.5	-35.20
Reflective paint/tiles for roof - 70% solar reflection	161	0	326	0	1.3	138.8	1.9	84.74
Reflective paint for external walls - 70-% solar reflection	251	0	326	0	1.93	138.8	2.7	92.96
External Shading Devices - Annual Average Shading Factor of 0.8	280	0	326	0	2.37	138.8	4.5	62.22
Insulation of Roof - U Value of 0.18	423	0	326	0	3.53	138.8	3.5	120.86
Insulation of External Walls - U Value of 0.27	1317	0	326	0	10.88	138.8	6.4	205.78

Table D.4: Energy Analysis (cont.)

Technology	Additional cost of technology (ZAR/unit)	Direct utility costs reduction (ZAR/ month)	Total utility cost (ZAR/ month)	Operational CO2 mitigation (tCO2/year)	Years till technology pays itself off	Electricity use (kWh/month)	Energy savings (%)	Rand spent per energy savings ratio (ZAR/%)
Low-E Coated Glass - U Value of 3 W/m² K and SHGC of 0.45	221	0	326	0	1.1	138.8	11.5	19.22
Higher Performance Glass - U Value of 2 W/m² K and SHGC of 0.28	391	0	326	0	3.33	138.8	16.9	23.14
Natural Ventilation	0	0	326	0	0	138.8	3.62	0.00
Ceiling Fans in all Habitable Rooms	167	-3.51	329.51	0	2.31	138.8	34.2	4.88
High Efficiency Boiler for Space Heating - Efficiency of 0.95	57	6.37	319.63	0.1	0.76	130.2	2.3	24.78
Solar Hot Water Collectors - 70% of Hot Water Demand	202	16.76	309.24	0.2	1	120.4	6.6	30.61
Heat Pump for Hot Water - COP of 1.5	490	13.97	312.03	0.2	2.92	123.5	5.5	89.09
Energy Efficient Refrigerators and Clothes Washing Machines	233	8.46	317.54	0.1	2.3	129.5	3.3	70.61

Table D.5: Energy Analysis (cont.)

Technology	Additional cost of technology (ZAR/unit)	Direct utility costs reduction (ZAR/ month)	Total utility cost (ZAR/ month)	Operational CO2 mitigation (tCO2/year)	Years till technology pays itself off	Electricity use (kWh/month)	Energy savings (%)	Rand spent per energy savings ratio (ZAR/%)
Energy-Saving Light Bulbs - Internal Spaces	45	2.34	323.66	0	1.6	136.3	1.1	40.91
Energy-Saving Light Bulbs - Outdoor Areas	60	1.87	324.13	0	2.67	138	1.3	46.15
Lighting Controls for Outdoor Lighting	150	0.58	325.42	0	21.38	138.2	0.2	750.00
Solar Photovoltaics - 25% of Total Energy Demand	477	37.9	288.1	0.4	1.05	97.2	14.7	32.45
Smart Meters	267	7.26	318.74	0.1	3.06	130.8	4.5	59.33

Table D.6: Floor Slabs Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: In-situ reinforced conctrete slab	0.00	0.00	0.00
Composite in-situ concrete and steel deck (permanent shuttering)	26520	7611.24	10.18
Concrete beam vault	14020	4023.74	7.86
Concrete filler slab	19520	5602.24	5.40
Hollow core precast slab	-9220	-2646.14	-2.60
In-situ concrete with >25% Groung Granulated Blast Slag	-9220	-2646.14	1.30
In-situ concrete with >30% PFA	6150	1765.05	1.70
In-situ trough concrete slab	23240	6669.88	6.40
In-situ waffle concrete slab	9889	2838.14	2.70
Light gauge steel floor cassette	11040	3168.48	3.00
Precast concrete double tee floor units	7020	2014.74	1.90
Precast RC planks and joist system	19720	5659.64	5.40
Thin precast concrete deck and composite in-situ slab	17100	4907.70	4.70
Timber floor construction	37550	10776.85	10.30

Table D.7: Roof Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: In-situ reinforced concrete roof slab	0.00	0.00	0.00
Aluminium sheets on steel rafters	5039.86	1446.44	2.30
Aluminium sheets on timber rafters	7682.99	2205.02	3.51
Asphalt shingles on steel rafters	28113.11	8068.46	12.30
Asphalt shingles on timber rafters	32738.64	9395.99	14.96
Brick panel roofing system	-18650.70	-5352.75	-8.52
Clay roofing tiles on steel rafters	23512.66	6748.13	10.72
Clay roofing tiles on timber rafters	28138.19	8075.66	12.86
Composite in-situ concrete and steel deck (permanent shuttering)	22706.71	6516.83	10.38
Composite slim floor slabs with steel I-beams	19661.40	5642.82	9.00
Concrete filler slab with Polystyrene blocks	17970.73	5157.60	8.21
Concrete filler slab	19953.61	5726.69	9.12
Copper sheets on steel rafters	5294.74	1519.59	2.42
Copper sheets on timber rafters	7937.87	2278.17	3.63
Ferro cement roofing channels	10656.09	3058.30	4.87
Hollow core precast slab	11433.49	3281.41	5.22
In-situ concrete with >25% GGBS	14627.88	4198.20	6.68
In-situ concrete with >30% PFA	15138.72	4344.81	6.92
In-situ trough concrete slab	21291.69	6110.72	9.72
In-situ waffle concrete slab	16485.66	4731.38	7.53
Micro concrete tiles on steel rafters	28327.19	8129.90	12.94
Micro concrete tiles on timber rafters	32952.72	9457.43	15.06
Precast concrete double tee floor units	15626.48	4484.80	7.14
Precast RC planks and joist system	20022.34	5746.41	9.14
Steel (zinc or galvanized iron) sheets on steel rafters	20939.18	6009.54	9.57
Steel (zinc or galvanized iron) sheets on timber rafters	23582.32	6768.13	10.78
Thin precast concrete deck and composite in-situ slab	171.00	49.08	0.02

Table D.8: External Wall Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: common brick wall with internal and external plaster	0.00	0.00	0.00
3-D concrete with 'shot-crete' both sides	74106.22	21268.49	33.86
Aluminium profile cladding	41827.82	12004.58	19.11
Autoclaved aerated concrete blocks	72069.01	20683.81	32.93
Brick faced precast concrete sandwich panel (insulation elsewhere)	25866.36	7423.65	11.82
Cellular lightweight concrete blocks	76818.63	22046.95	35.10
Cement fibre boards on metal studs	76323.72	21904.91	34.87
Cement fibre boards on timber studs	85943.27	24665.72	39.27
Clay tiles cladding (or 'terracotta rainscreen cladding') on metal studs	65558.89	18815.40	29.95
Compressed stabilised earth blocks	78392.00	22498.50	35.82
Cored (with holes) bricks with internal and external plaster	44479.41	12765.59	20.32
Curtain walling (opaque element)	22886.90	6568.54	10.02
Exposed cored (with holes) bricks with internal and external plaster	42903.54	12313.32	19.60
Facing brick and hollow concrete blocks	35269.12	10122.24	16.12
Facing brick and solid concrete blocks	31845.47	9139.65	14.55
Facing brick and timber stud	28227.83	8101.39	12.90
FaLG block	63821.78	18316.85	29.16
Ferrocement wall panel	54870.38	15747.80	25.07
Fly-ash stabilised soil blocks	83666.52	24012.29	38.23
GGBS stabilised soil blocks	84447.90	24236.55	38.59
Glass reinforced concrete cladding (insulation elsewhere)	61663.26	17697.36	28.17
Honeycomb clay blocks with internal and external plaster	70949.23	20362.43	32.42
Medium weight hollow concrete blocks	76676.39	22006.12	35.03

Table D.9: External Wall Material Analysis (cont.)

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Phosphogypsum panel	61734.85	17717.90	22.29
Plasterboards on metal studs	59919.01	17196.76	21.64
Plasterboards on timber studs	66869.17	19191.45	24.15
Polymetric render on brick	19667.94	5644.70	7.10
Polymetric render on concrete block	63350.73	18181.66	22.88
Precast concrete panels	31293.74	8981.30	11.30
Precast concrete sandwich panel (insulation elsewhere)	41670.61	11959.47	15.05
Rammed earth blocks/walls	69480.50	19940.90	25.09
Solid dense concrete blocks	53399.52	15325.66	19.28
Steel profile cladding	52790.50	15150.87	19.06
Stone faced precast sanwich panel (insulation elsewhere)	52790.50	15150.87	12.13
Stone profile cladding	49259.62	14137.51	17.79
Straw bale blocks	68565.42	19678.28	24.74
Timber weatherboard on timber studs	67447.89	19357.54	24.36

Table D.10: Internal Wall Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: Common brick wall with palster both sides	0.00	0.00	0.00
3-D concrete with 'shot-crete' both sides	23332.24	6696.35	10.66
Cellular lightweight concrete blocks	33141.70	9511.67	15.14
Cement fibre boards on metal studs	25549.70	7332.76	11.67
Cement fibre boards on timber studs	35169.29	10093.59	16.07
Compressed stabilised earth blocks	33278.80	9551.02	15.21
Cored (with holes) bricks no finish	16055.29	4607.87	7.34
Cored (with holes) bricks with internal and external plaster	19207.02	5512.41	8.78
FaLG block	27559.41	7909.55	12.59
Ferrocement wall panel	19770.04	5674.00	9.03
Fly-ash stabilised soil blocks	35556.44	10204.70	16.25
GGBS stabilised soil blocks	35893.87	10301.54	16.40
Honeycomb clay blocks with internal and external plaster	30637.17	8792.87	14.00
Medium weight hollow concrete blocks	33110.26	9502.64	15.13
Plasterboards on metal studs	22267.36	6390.73	10.17
Plasterboards on metal studs with insulation	20624.34	5919.19	9.34
Plasterboards on timber studs	31886.92	9151.55	14.57
Plasterboards on timber studs with insulation	30546.92	8766.97	13.96
Precast concrete panels	11501.12	3300.82	5.26
Precast concrete sandwich panel	24541.06	7043.28	11.21
Rammed earth blocks/walls	37026.03	10626.47	16.92
Solid dense concrete blocks	28976.60	8316.28	13.24
Straw bale blocks	28976.60	8316.28	16.16

Table D.11: Surface Bed Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: Ceramic tile	0.00	0.00	0.00
Cork tile	2170.58	622.96	0.99
Finished floor concrete	1813.25	520.40	0.83
Laminated wooden flooring	-1086.70	-311.88	-0.50
Linoleum sheet	786.24	225.65	0.36
Nylon carpets	-498.21	-142.99	-0.23
Parquet/wooden block finishes	789.75	226.66	0.36
Plant fibre (seagrass, sisal, coir and jute) carpet	1971.22	565.74	0.90
Stone tiles/slabs	-904.18	-259.50	-0.41
Terracotta tiles	-718.85	-206.31	-0.33
Terrazzo tiles	1401.08	402.11	0.64
Vinyl flooring	489.72	140.55	0.22

Table D.12: Window Frame Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: Aluminium	0.00	0.00	0.00
Aluminium clad timber	6290.95	1805.50	2.87
Steel	5382.93	1544.90	2.46
Timber	7863.69	2256.88	3.59
UPVC	4973.73	1427.46	2.27

Table D.13: Roof Insulation Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: no insulation	0.00	0.00	0.00
Air gap <100mm wide	0.00	0.00	0.00
Air gap >100mm wide	0.00	0.00	0.00
Cellulose	-203.00	-58.26	-0.60
Cork	-1495.00	-429.07	-4.10
Glass wool	-296.00	-84.95	-0.80
Mineral wool	-482.00	-138.33	-1.30
Polystyrene	-826.00	-237.06	-2.30
Polyurethane	-1968.00	-564.82	-5.40
Woodwool	-5765.00	-1654.56	-15.90

Table D.14: Wall Insulation Material Analysis

Technology	Embodied energy savings (MJ)	Indirect electricity savings (kWh)	Material savings (%)
Base case: none	0.00	0.00	0.00
Air gap <100mm wide	0.00	0.00	0.00
Air gap >100mm wide	0.00	0.00	0.00
Cellulose	-60.90	-17.48	-1.80
Cork	-460.90	-132.28	-12.70
Glass wool	-91.30	-26.20	-2.50
Mineral wool	-109.90	-31.54	-3.00
Polystyrene	-254.70	-73.10	-7.00
Polyurethane	-606.80	-174.15	-16.70
Woodwool	-1778.10	-510.31	-49.00